



American Water Works Association
RESEARCH FOUNDATION

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Final Report of the Perchlorate Research Issue Group Workshop

**September 30 - October 2, 1997
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**Funded By:
East Valley Water District
Main San Gabriel Basin Watermaster
Metropolitan Water District of Southern California
San Bernardino Valley Municipal Water District
Southern Nevada Water Authority**

Final Report of the Perchlorate Research Issue Group Workshop

Table of Contents

Background -----	1
Workshop Design-----	2
The Participants-----	3
Utility and Regulatory Requirements-----	5
Workshop Research Recommendations Matrix-----	5
Presentation Summaries	
Major Dan Rogers – Perchlorate Health Effects-----	6
Frank Blaha – Perchlorate Occurrence in the Environment -----	7
Joseph Donnelly – The New Analytical Method and Related Issues-----	8
Mike Girard – Aerojet’s Experience with Development of a Perchlorate Treatment Process -----	9
Jim Hurley – Perchlorate Treatment Process Developed at Tyndall Air Force Base -----	10
Ravi Upadhye – Carbon Aerogel -----	11
Kevin Mayer – Summary Overview of Prospects for Other Treatment Technologies (Non-biological) -----	12
John Catts – Treatability of Perchlorate in Groundwater-----	14
Proposed Research Projects (Project Matrix)-----	17
Application of Bioreactor Systems to Low-concentration Perchlorate Contaminated Water -----	19
Treatability of Perchlorate-Containing Waters by Reverse Osmosis and Nanofiltration -----	23
The Treatability of Perchlorate in Groundwater Using Ion Exchange Technology -----	27
Survey the Performance of the California DHS (Ion Chromatography) Analytical Protocol -----	31
Short Term Perchlorate Laboratory Issues -----	33
Removal of Perchlorate and Bromate in Conventional Ozone/GAC Systems -----	35
Investigation of Methods for Perchlorate Destruction in Aqueous Waste Streams -----	39
Assessment of Enzyme Based Reactor Systems on Perchlorate Reduction -----	41
Literature/Expert Panel Review for Effective In-situ Treatment Technologies for Treatment of Perchlorate in Soil and Groundwater -----	43
Demonstration of Electrodialysis and Electrodialysis Reversal as a Control Technology for Perchlorate-Containing Waters -----	47
Investigation of Innovative Technologies for Perchlorate Removal from Drinking Water Sources -----	51
Development of an Alternative Analytical Method for Measuring Perchlorate Ion at the 4 PPB Level -----	55
Inter-Laboratory Study for the Performance Evaluation of the Cal-DHS Method: Determination of Perchlorate by IC -----	57
Fate and Transport of Perchlorate in Drinking Water Sources -----	59
Assess the Current Regional Health Effects Associated with Perchlorate in Ground and Surface Water Supplies -----	63
Perchlorate Teleconference -----	65
Develop Literature Database and Communication Tools and Distribute to Water Utilities to Keep Customers Informed of Perchlorate Issue -----	69
Appendix 1 – Agenda-----	1-1
Appendix 2 – Perchlorate Issue Group-----	2-1

Final Report of the Perchlorate Research Issue Group

BACKGROUND

In recent months perchlorate has become a drinking water issue in the State of California. A new analytical procedure developed by the California Department of Health Services (CDHS) has reduced the detection limit to perchlorate from 400 parts per billion (ppb) to 4 ppb. This new method was first developed in March 1997. Based on United States Environmental Protection Agency (EPA) work reviewing the toxicology of perchlorate, which recommended reference dose levels of perchlorate in drinking water from 4-18 ppb, CDHS adopted a provisional action level of 18 ppb for perchlorate in drinking water. Using the new method, the CDHS had, by June 1997, sampled 232 ground water wells and found perchlorate in 69 of them in various concentrations. Twenty of these wells contained perchlorate above the State's provisional action level of 18 ppb. Additional sampling is planned, both in California and elsewhere.

Perchlorate (ClO_4) is the oxidation product of chlorate (ClO_3). It appears in such compounds as ammonium perchlorate, potassium perchlorate, sodium perchlorate, and perchloric acid. It is highly reactive in its solid state and as ammonium perchlorate it is used as the oxidizer in solid rocket fuel. Because of its limited shelf life, it must be periodically washed out of the country's missile and rocket inventory and replaced with a fresh supply. Thus, large volumes of the compound have been disposed of in California and presumably other sites, since the 1950's. Perchlorate is also used in certain munitions, fireworks, the manufacture of matches, and in analytical chemistry. It should be noted that, reactive as it is, the compound is extremely stable when dissolved in water at concentrations as high as 1,000 mg/L.

The health effects of perchlorate are of obvious concern because it has been used for some time to treat persons with Graves' disease. Relatively high doses inhibit the normal function of the thyroid gland. Its effects at low dose exposures are not known. The U.S. Air Force, with additional support from perchlorate manufacturers and users, is undertaking a 90 day single generation rat study and a 30 day second generation rat study. Although this work will investigate effects beyond the thyroid, it is not expected to provide definitive answers to all toxicological questions.

The new analytical method, which is an ion chromatography method, has not yet been widely tested or peer-reviewed. Therefore, as promising as it is, it requires scientific confirmation and the support of an acceptable alternative method. Because analytical methods are critical to determining occurrence levels in drinking water supplies, the urgent need for analytical developmental work is evident.

Current and recent research into treatment methods to remove perchlorate have concentrated on highly contaminated sites, with water containing 8,000 to 9,000 ppb, or higher concentrations, of the compound. Region IX of the EPA, the CDHS, the Air Force, and others have been reviewing the literature and searching for perchlorate treatment methods effective at the levels being found in drinking water supplies. Their consensus at this time is that there is no proven removal process available at the low concentrations being found in drinking water. Aerojet, a significant user of perchlorate, is developing a proprietary bioremediation system. The Air Force, in cooperation with the industry, is also working on biological treatment processes. Conventional practices with GAC, ion

exchange, air stripping, and advanced oxidation had limited or no effect on low concentrations of perchlorate. Reverse osmosis may be effective but the ratio of effluent water to rejected water is unknown. The issue of perchlorate residual disposal is a serious concern in all methods.

The combination of these unresolved issues, especially the lack of a treatment technology, attracted Congressional interest in recent months, particularly in the California delegation. Through efforts led by Rep. Jerry Lewis (R., Calif.) the House-Senate Conference Committee on Appropriations on September 30 earmarked \$2,000,000 for the East Valley Water District, San Bernardino, CA, for research into treatment methods for perchlorate. In anticipation of this funding, the East Valley Water District, in cooperation with four other water suppliers, (Main San Gabriel Basin Watermaster, Metropolitan Water District of Southern California, San Bernardino Valley Municipal Water District, and the Southern Nevada Water Authority) sponsored a research planning workshop which they requested the AWWA Research Foundation (AWWARF) to organize and manage. The AWWARF staff agreed and convened an expert workgroup that included CDHS, EPA Region IX, university professors and researchers, Aerojet and the Air Force, consultants and other research experts, as well as technical representatives of the sponsoring water utilities. Using a modification of the planning process for other AWWARF research issue groups, the Foundation conducted the perchlorate workshop in Ontario, CA, September 30-October 2, 1997. This report is the outcome of that workshop.

WORKSHOP DESIGN

The workshop program and schedule is included in this report as Appendix I. Briefly explained, the workshop design consisted of the following elements:

- Group introductions; background information on workshop sponsorship, purposes, and objectives; ground rules.
- A series of seven brief presentations:
 - Summary of current health effects information by Major Dan Rogers, U.S. Air Force
 - Overview of occurrence studies, recent and planned, by Frank Blaha, AWWA Research Foundation
 - New analytical method and related issues by Joe Donnelly, USEPA National Exposure Research Laboratory
 - Aerojet bioremediation method by Mike Girard, Aerojet
 - Air Force bioremediation research by Jim Hurley, Tyndall Air Force Base/Armstrong Laboratory
 - Lawrence-Livermore National Laboratory research by Ravi Upadhye, Lawrence Livermore National Laboratory
 - Overview of prospects for other treatment technologies by Kevin Mayer, USEPA
- An eighth briefing was added on a just-completed survey of treatment methods by consultants working with Aerojet on the San Gabriel Superfund site. This site is impacted by perchlorate as well as other contaminants. In addition, the site impacts portions of the source water for the San Gabriel area in California. This briefing was done by John Catts of Harding Lawson Associates.
- The large group was then split into three concurrent smaller workgroups--Analytical Methods and Occurrence, Utility and Regulatory Requirements, and Treatment Options. Each of these individual groups identified research needs which were then presented to the whole group for discussion and refinement. The utility group also listed operational requirements for proposed treatment processes.

- Based on the comments of the large group, the smaller workgroups met again to draft detailed project descriptions.
- Seventeen project descriptions were reproduced for review by all participants. These project descriptions included a description of the anticipated project scope and a suggested budget. Suggested changes were discussed in a large group session which concluded with agreement on all projects to be recommended by the workshop. Two education/information projects are to be referred to the American Water Works Association for action.
- The participants then developed a matrix in which each project was assigned a priority and a start-up year. This matrix is included below in this report, covering the remaining 15 projects.

THE PARTICIPANTS

Complete names, titles, and addresses of all participants may be found in Appendix II of this report. The roster, broken down by type of organization represented, included:

Utility Representatives

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Laboratory Director
City of Pasadena

Robert Martin
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Fred Hicks, Ph.D.
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Issue Group Facilitator

John B. Mannion
Management Consultant

PRESENTATION SUMMARIES

The following pages contain the summary highlights or main points of the eight presentations or briefings that provided a common starting point for the workshop participants.

UTILITY AND REGULATORY REQUIREMENTS

The workgroup that met under this heading had as one of its assignments the identification of practical operational criteria for any perchlorate treatment methods that might be developed. The list they generated was accepted by the other participants as valid, if ideal, criteria. The workgroup's report included:

- Effective treatment methods should be sought to reduce perchlorate contamination of drinking water to 4 ppb.
- Disposal of any residuals generated by a perchlorate treatment technology should be considered as a key treatment technology variable.
- Perchlorate contamination is already impacting many water utilities. Therefore, research on perchlorate treatment should consider and address real water matrices that can consist of a number of different contaminants that impact treatment. The interplay of various common, or expected, contaminants in perchlorate-contaminated water must be addressed.

WORKSHOP RESEARCH RECOMMENDATIONS MATRIX

The table on page 17 lists the research topics developed by the workshop, displays the priority ranking assigned to each, the estimated funding required (in thousands), and the recommended start-up year. It should be noted that due to the urgency of the perchlorate issue, some of the projects identified by this issue group are large multi-phased projects covering a number of scales from bench-scale to pilot-scale, etc. This approach was taken so that treatment methods showing promise could be taken from the conceptional stage all the way to full-scale application in as little time as possible.

Perchlorate Health Effects

By Major Dan Rogers

- EPA's 1992 and 1995 work related to perchlorate reached a provisional reference dose for perchlorate in drinking water of 4 to 18 micrograms per liter following typical EPA protocol. However, many uncertainties remain. The main uncertainties related to: the short-term nature of the studies done to date; uncertainties related to sensitive individuals; and, data uncertainties.
- California has adopted the 18 microgram per liter concentration as a provisional action level for perchlorate in drinking water.
- More information on the toxicology of perchlorate could result in an increased acceptable concentration of perchlorate in drinking water.
- The Air Force, in association with others, has initiated additional toxicological studies on perchlorate. At this time approximately \$1.4 million is committed to this work.
- This additional toxicological work will include a 90-day single generation rat study. This study meets the EPA requirements for such a study. In addition, a 30 day second generation rat population will also be studied.
- Although the toxicological work is expected to confirm that the thyroid is the target organ, this new work will look at other potential toxicological effects of perchlorate.
- An 11-member panel of experts and stakeholders developed the study protocol for this new toxicological work. This panel will also monitor the toxicological work as it is completed. This panel is being added to as additional stakeholders and experts are identified. There are currently 13 members of the panel. Membership currently includes many stakeholders from the California/Nevada area, including regulatory agencies and academia.
- It is felt that the high priority toxicological questions related to perchlorate are being addressed by this new toxicological work. Toxicological wish list questions still remain.
- The Air Force toxicological technical work is being overseen by Toxicological Excellence for Risk Assessment (TERA).

Perchlorate Occurrence in the Environment

By Frank Blaha

California water utilities and the California Department of Health Services (CDHS) have done the most work on the occurrence of perchlorate in the environment. This work has mostly been done since development in early 1997 of a new analytical method for perchlorate. This method is capable of much reduced detection limits compared to earlier methods. The AWWA Research Foundation has done no direct new work on the occurrence of perchlorate in the environment, but we are aware of most of the work that has been done by others. One reason little work has been done on the occurrence of perchlorate in the environment is that this compound is not a regulated contaminant. This lack of data also means that we know little about the behavior of perchlorate in the environment. Retardation factors, chemical and biological immobilization or treatment, and binding of perchlorate to soils are all essentially unresearched.

The new work on perchlorate in the environment started in California at a site that was known to have perchlorate present, but the distribution of this contaminant was limited based on the earlier detection limits. With the newer detection limits the contaminant was found to be much more widespread than previously understood. This prompted the CDHS to look for perchlorate elsewhere. By late June of 1997 perchlorate had been analyzed in 232 groundwater wells, with detections in 69 wells, and 24 wells above the CDHS provisional action level of 18 micrograms per liter. Partly due to the prevalence of perchlorate contamination at California sites, Nevada and Utah have done some limited occurrence work and have found environmental perchlorate contamination. The presence of perchlorate contamination has also been confirmed in portions of Lake Mead and downstream from Lake Mead in Colorado River water. The Environmental Protection Agency and the Metropolitan Water District of Southern California did some preliminary work to ascertain how prevalent perchlorate contamination might be across the country. They identified 26 sites with possible perchlorate usage in 14 states using Standard Industrial Classification code 3764, "Space Propulsion Units and Parts." Although there is increasing concern amongst various state regulatory agencies and federal agencies, there is currently no comprehensive program to address the occurrence of perchlorate in the environment.

The New Analytical Method and Related Issues

by Joseph Donnelly

The California Department of Health Services (CDHS) has developed an interim analytical method protocol for perchlorate. The method detection limit of 0.7 ppb in reagent water addresses the desired 4 ppb detection limit in aqueous environmental matrices, and an 18 ppb action level. This ion chromatographic (IC) method has been used to detect perchlorate in water supplies in California, Arizona, and Nevada. Goals for an analytical method include that it be simple, rugged, use widely-available equipment and expertise, be cost-effective, reliable, and produce data of known and adequate quality.

The CDHS method uses a strong base eluant. Strong acid is used to regenerate the column after analysis. The column is an anion-exchange type, from which perchlorate elutes relatively late (about 7.5 minutes retention time). A general conductivity detector is used.

The potential for false positives and negatives should be studied. Potential analytical interferences could include iodide, bromate, iodate, thiocyanate, sulfate, and nitrate anions. The ion chromatographic retention time of perchlorate shifts with concentration. For example, one research group reported a retention time of 35 minutes for a 50 ppm solution. This time was shortened to 20 minutes for a 2 parts-per-thousand solution. Confirmatory analytical techniques would be desirable, both qualitative (identity) and quantitative (precision and accuracy).

Other methods for perchlorate analysis are available, but either are not suitable or have not been optimized for trace-level environmental analysis. Capillary electrophoresis has been applied to perchlorate analysis in the ppm concentration level, with general detectors, such as ultraviolet, and with specific detectors such as Raman or mass spectrometric. Electrospray mass spectrometry has also been used to detect perchlorates.

The following capabilities of the CDHS method should be defined: confirmation of analyte identity, and absence of interference (false positives, false negatives); single and multiple laboratory precision and accuracy; matrix effects such as dissolved solids/conductivity. Sample holding times and sample preservation should also be investigated.

One goal for future research is to determine the stability of perchlorate in the environment, particularly aqueous ecosystems. The thermodynamics of perchlorate decomposition are favorable; it is potentially a powerful oxidizer. The kinetics are slow at ambient temperatures and in the absence of catalysis. Whether biological systems provide biochemical catalysts has not been found to date in the literature search. This question is key to answering concerns about the relative toxicity of the perchlorate anion in drinking water.

In summary, several laboratory-based studies of the Cal-DHS method would be worthwhile.

- detection limit validation in aqueous matrices.
- verification of method performance with high dissolved solids.
- method precision, intro- and inter-laboratory.
- method accuracy vs. confirmatory analysis results.
- sample stability and preservation study vs. holding times.

Aerojet's Experience with Development of a Perchlorate Treatment Process

by Mike Girard

Aerojet had started on development of a treatment process for perchlorate a few years ago. The intent was to develop a process to concentrate, and then treat, the perchlorate. The waste stream to be treated had 7,000-9,000 micrograms per liter of perchlorate, and treatment down to 400 micrograms per liter was desired. A treatment screening of 20 separate treatment methods was narrowed down to five treatment methods to be reviewed in more detail. These five methods were: reverse osmosis, ion exchange, activated carbon, electrodialysis, and bioremediation.

Considerable development effort was devoted to ion exchange for the next two years. Four resins were studied in detail. It was found that some resins would not release perchlorate even during resin regeneration activities.

Development work was also devoted to development of a biological treatment system. Two years of effort were spent in reviewing a number of different biological treat systems: fixed films, fluidized bed, etc. By April of 1996 Aerojet had developed a fluidized bed, anoxic biological treatment system capable of reducing perchlorate concentrations down to 100 microgram per liter concentrations. At this time Aerojet is moving forward with design and construction of a 1,500 gallon per minute full scale treatment system at their Ranch Cordova site. Aerojet is also working on the application of this biological treatment system to perchlorate-containing waters of varying quality. Aerojet is considering the licensing of this treatment technology to others. Therefore, the design details of this process cannot be released at this time.

Perchlorate Treatment Process Developed at Tyndall Air Force Base

by Jim Hurley

The work at Tyndall AFB was prompted by the need for a wastewater treatment process to treat wastewaters generated by re-graining solid rocket waters. A cooperative research and development agreement was entered into with the Thiokol Company who will do the actual re-graining work. This biological treatment process was well-described in the materials distributed prior to the issue group meeting. The system consists of a two-step process, an anaerobic reactor followed by an aerobic reactor. Development work on this process progressed from laboratory scale, to bench scale, to a pilot scale facility. At this time the pilot-scale treatment facility is being shipped to the Thiokol plant in Brigham City, Utah, where it will be assembled again for use in a production scenario. The perchlorate is reduced to chloride and oxygen, and has been successfully applied to 9,000 milligrams per liter perchlorate concentrations reducing the perchlorate to less than 500 milligrams per liter detection limit. The system has not been tested with the new, reduced detection limit, but will probably prove effective in treatment to lower concentrations.

The residence time in the reactor can vary from 6-48 hours, depending how you want to manage the nutrient feed and the reactors. For the high concentrate wastewaters investigated to date a constant-stirred tank reactor has worked well, but in the low-concentration drinking water systems a fixed-bed reactor may be more effective.

Carbon Aerogel

by Ravi Upadhye

The Lawrence Livermore National Laboratory has been working on the application of carbon aerogel (an air-filled carbon gel) to real-world problems. However, this technology is still very much in the research and development stage. These open-pore solids have potential applications to perchlorate contamination, working in a capacitive deionization process. The carbon aerogels are suitable for this type of application due to their large surface area (400 to 1,000 square meters per gram) and high porosity. Contaminates are held by electrical forces, not adsorption as in activated carbon treatment processes.

However, the difficulties associated with carbon aerogel technology include backflushing difficulties in which only 40-60% regeneration is achieved. This relatively low regeneration rate combined with the high cost of carbon aerogel make it impractical at this time. Carbon aerogel has been laboratory-tested for treatment of 80 milligrams per liter perchlorate-contaminated waters. Perchlorate concentrations were successfully reduced to ten milligrams per liter. There has been no testing of perchlorate removal on real waters to date.

Summary Overview of Prospects for Other Treatment Technologies (Non-biological)

by Kevin Mayer

A number of physical and chemical processes to treat perchlorate-contaminated water are under consideration and a number of them have been tested to a certain extent. The U.S. Environmental Protection Agency has not conducted treatability studies directly although we are in a position to learn about the work underway at various cleanup sites in California and Nevada. These sites include the Aerojet Superfund Site near Sacramento, a portion of the San Gabriel Valley Superfund Site in southern California, the Kerr-McGee manufacturing facility in Nevada and a demonstration treatment project conducted for the Main San Gabriel Basin Watermaster. The results of the investigations are neither formally published nor in a format that would bear critical examination but the information can be useful at this early stage of the search for a solution.

No proven breakthroughs stand out for treatment of large volumes of water at relatively low concentrations of perchlorate. Several critical factors must be considered in assessing treatment technologies. The influent concentration, the desired effluent concentration and the flow rate or volume of water to be treated are three factors that distinguish an industrial waste treatment from water supply treatment. A technology that may be feasible for treating tens or hundreds of gallons a day may be unfeasible for million-gallon-per-day flows. Disposal of wastes generated from the treatment process is another consideration. The cost to construct and operate any treatment option becomes a tremendously important consideration when dealing with the large volumes of water in urban water systems or major groundwater cleanup projects.

The chemistry of perchlorate would seem, at first glance, to be immensely favorable to chemical reduction processes. Perchlorate is the most highly oxidized species of chlorine. The chlorine in perchlorate is at an oxidation state of plus seven which is remarkably higher than the minus one oxidation state of chloride – the most stable form of chlorine in water. Thermodynamically, perchlorate should react readily with reduced compounds. Other chemical factors contribute to the chemical stability of dissolved perchlorate. The four oxygens surrounding the chlorine account for all eight electrons filling the outer electron shell. Additionally, the tetrahedral packing of the four oxygen atoms around the chlorine atom distributes the charge evenly around a relatively large surface area. A sizable activation energy is necessary to disrupt the stable structure of perchlorate to allow the thermodynamically favorable reduction to proceed. Biological systems apparently can overcome this activation energy barrier as they do for so many other reactions.

Perchlorate-containing salts readily dissociate in water to form the perchlorate anion, and perchlorate is nearly as soluble as table salt. This eliminates the use of volatilization technologies such as the air-stripping treatment commonly used for volatile organic contamination.

Granular Activated Carbon (GAC) filtration is another common water treatment technology which is not effective for perchlorate. The experience of water systems in California show some

initial adsorption, similar to the adsorption of nitrate, followed by breakthrough too rapid to be economical.

Other adsorptive technologies, such as ion exchange, have not been extensively tested for perchlorate, primarily due to the expense of the method estimated from the initial trials. I understand that there are resins that do adsorb perchlorate although a cost-effective system has not been developed. There has been little enthusiasm for ion exchange which is seen as a prohibitively expensive treatment technology from a water supplier's perspective.

The same can be said for reverse osmosis or nanofiltration technologies. Physically and chemically, reverse osmosis should be as effective for removing perchlorate as for removing smaller anions like chloride. The cost of construction, operation and waste disposal for systems treating large volumes of water for low concentrations of perchlorate is considered too great right now. I am not aware of any studies conducted to develop perchlorate-specific costs.

Chemical reactions have been tried using a variety of reducing agents, but none have shown promise at the bench scale. Attempts at chemical reduction by reduced iron, 'enhanced iron', iron pyrite, and various sulphur compounds have been unsuccessful. A palladium catalyst for forming highly reactive hydrogen has not worked for perchlorate, although it is successful for reducing chlorinated organics. I do not know of any attempts at electrochemical reduction or addition of energy such as ultraviolet radiation to destabilize perchlorate.

One observation of fortuitous reduction of perchlorate has been reported in a preliminary fashion without either corroboration or satisfactory chemical explanation yet. A 1,000 gallon-per-minute demonstration system was constructed at a San Gabriel Valley well contaminated with several chlorinated solvents to test pretreatment by an advanced oxidation process in series with GAC treatment units. Substantial decrease in perchlorate concentration was observed, although neither advanced oxidation nor GAC alone could explain the observation. The vendor of the system is working to confirm and elucidate the phenomenon.

Treatability of Perchlorate in Groundwater

By John Catts

As a part of ongoing Superfund actions, a detailed review and screening was done to identify potential methods for treatment of perchlorate-contaminated groundwater. This work was performed by Harding Lawson Associates for application to the Baldwin Park Operable Unit. It built upon earlier technology screening work that had been conducted by Aerojet in 1994 and 1995. This Aerojet work has resulted in the development of a biological treatment system that is currently being applied at a full-scale size to perchlorate contamination at the Rancho Cordova Superfund site. The "Draft Technology Screening for the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin" was completed in draft form on September 29, 1997, the day before the Issue Group convened. An outline of the basic screening activities follows.

Literature/Patent Review

- Dialog – On-line Search
 - 152 databases
 - 20 key words
- Biological Methods
- Physical Methods
 - Six methods
- Chemical Methods

Initial Technology Screening

- Seven methods
- Biochemical Reduction
- Activated Carbon Adsorption
- Ion Exchange
- Capacitive Deionization
- Gettering Reversibly Dispersible Carriers
- Reverse Osmosis
- Electrodialysis
- Chemical Oxidation
- Supercritical Water Oxidation
- Chemical Reduction

Initial Technology Screening (Continued)

- Electrochemical Reduction
- Catalyzed Chemical Reduction
- Photocatalytic Reduction
- Chemical Precipitation

Screening Criteria

- Effectiveness
 - Potable effluent
 - Protection of health
 - Reliability
- Implementability
 - Proven technology
 - Space needs
 - Health and safety
- Cost
 - Development
 - Capital
 - Operations and maintenance
- Acceptance

The results of the Screening Activities are presented in Table 5-3, reproduced here, from the "Draft Technology Screening" document. A detailed technology screening, including a conceptual design and cost evaluation, was then conducted on the most promising of the identified technologies. The results of this work are presented in Table 6-8, reproduced here, from the "Draft Technology Screening" document.

Table 5-3 Summary of Technology Screening Alternatives Scores

Alternative Number	Technology	Effectiveness	Implementability	Cost	Acceptance	Total Score (out of 50)
A-1	Biochemical Reduction	13	15	15	3	46
A-2	Activated Carbon	11	9	7	3	30
A-3	Ion Exchange	13	13	13	5	44
A-4	Capacitative Deionization	11	7	9	3	30
A-5	Gettering with Reversibly Dispirsable Carriers	3	5	7	1	16
A-6	Reverse Osmosis	13	13	9	5	40
A-7	Electrodialysis	11	15	9	5	40
A-8	Chemical Oxidation	7	11	3	5	26
A-9	Supercritical Water Oxidation	9	3	3	3	18
A-10	Chemical Reduction	5	9	7	1	22
A-11	Electrochemical Reduction	7	9	5	3	24
A-12	Catalyzed Chemical Reduction	5	9	7	3	24
A-13	Photocatalytic Reduction	3	5	3	1	12
A-14	Chemical Precipitation	5	9	7	1	22

Detailed cost analyses will be presented in Section 6 for the six top-ranking technologies identified in bold type above

Table 6-8 Summary of Cost Estimates

Treatment Method	Total Capital Cost	Annual O&M Cost	Total Annual Treatment Cost		Normalized Treatment Cost
	(\$Million)	(\$Million)	(\$Million)	(\$/kgal)	
Biological with GAC/FB	35	3.0	6.6	0.60	1.0
Ion Exchange	28	5.5	10.4	0.95	1.6
Liquid Phase GAC	46	16.0	20.7	1.88	3.1
Electrodialysis	84	5.0	13.6	1.06	2.1
Reverse Osmosis	65	10.0	16.6	1.52	2.5
Capacitive Deionization	131	3.0	16.6	1.52	2.5

Notes:

1. Total annual treatment cost determined by adding annual O&M cost and total capital cost amortized over 20 years at 8%.
2. All Costs are in 1997 dollars.
3. All costs are order-of-magnitude only accurate to within plus or minus 50 percent.
4. Costs of land and related environmental requirements are not included.

Proposed Research Projects Developed by the Perchlorate Issue Group September 30-October 2, 1997

Group	Project Title	Project Number	Priority Ranking	1998	1999	2000	2001
Treatment	Application of Bioreactor Systems to Low-concentration Perchlorate Contaminated Water	1	1	688		320	
Treatment	Treatability of Perchlorate-Containing Waters by Reverse Osmosis and Nanofiltration	4	1	312		513	
Treatment	The Treatability of Perchlorate in Groundwater Using Ion Exchange Technology	9	1	312		513	
Analytical Methods	Survey the Performance of the California DHS (Ion Chromatography) Analytical Protocol	10	1	94			
Analytical Methods	Short Term Perchlorate Laboratory Issues	13	1	125			
Treatment	Removal of Perchlorate and Bromate in Conventional Ozone/GAC Systems	6	2	188	577		
Treatment	Investigation of Methods for Perchlorate Destruction in Aqueous Waste Streams	7	2	250		577	
Treatment	Assessment of Enzyme Based Reactor Systems on Perchlorate Reduction	2	3		385		1,090
Treatment	Literature/Expert Panel Review for Effective In-situ Treatment Technologies for Treatment of Perchlorate in Soil and Groundwater	3	3	63			
Treatment	Demonstration of Electrodialysis and Electrodialysis Reversal as a Control Technology for Perchlorate-Containing Waters	5	3		577		
Treatment	Investigation of Innovative Technologies for Perchlorate Removal from Drinking Water Sources	8	3		385	577	
Analytical Methods	Development of an Alternative Analytical Method for Measuring Perchlorate Ion at the 4 PPB Level	11	3			160	
Analytical Methods	Inter-Laboratory Study for the Performance Evaluation of the Cal-DHS Method: Determination of Perchlorate by IC	12	3		128		
Occurrence	Fate and Transport of Perchlorate in Drinking Water Sources	14	3	250	256		
Health Effects	Assess the Current Regional Health Effects Associated with Perchlorate in Ground and Surface Water Supplies	17	3		513	577	
	TOTAL			2,282	2,821	3,237	1,090

- 1 - Higher Priority Projects
2 - Medium Priority Projects
3 - Lower Priority Projects

TITLE: APPLICATION OF BIOREACTOR SYSTEMS TO LOW-CONCENTRATION PERCHLORATE-CONTAMINATED WATER

Description of Problem: No treatment process has been demonstrated for reducing perchlorate at low (less than 1,000 microgram per liter) concentrations to acceptable drinking water concentrations.

Objective of Research Response:

1. Evaluate the efficiency of a biological process to reduce perchlorate concentrations of up to 1,000 micrograms per liter to drinking water action levels of 4-18 micrograms per liter,
2. Evaluate the impact of co-contaminants, such as nitrate and volatile organic compounds (VOCs), on process performance, and
3. Characterize process effluents and define post treatment requirements.

Recommended Funding: Phase I: Up to two different (parallel) projects at \$190,000-\$375,000 each, which includes research costs as well as AWWARF project management costs. The total Phase I costs will not exceed \$688,000. These treatment technologies will be tested at the bench-scale level. **Phase II:** Up to two different (parallel) projects for a total cost of \$320,000, including research costs and AWWARF project management costs will be tested at the pilot scale. The Phase II activities of this multi-phase study are dependent upon the success of Phase I activities as well as the availability of Phase II funding. Duration: 24 months for each phase of the project.

Past and Ongoing Related Research: The treatment of perchlorate at concentrations less than 1,000 micrograms per liter is a relatively unresearched issue. A practical analytical method to detect concentrations of perchlorate less than 400 micrograms per liter has only recently been developed, accounting for this lack of research work. However, limited research has been done on the treatment of perchlorate at higher concentrations, and work is now starting on the treatment of perchlorate at lower concentrations.

Aerojet has conducted bench and pilot scale tests on a semi-proprietary biological treatment process for perchlorate at the Rancho Cordova Superfund site near Sacramento, California. These tests pre-date the development of the new analytical method, and are therefore only known to be effective to reduce perchlorate concentrations to 400 micrograms per liter. A full-scale treatment plant (1,500 gallons per minute) for perchlorate treatment is currently being designed for construction and operation at this site. This biological treatment method is also being investigated in studies related to the Baldwin Park Operable Unit of the San Gabriel Superfund site for removal of perchlorate down to 4 micrograms per liter. A two-phase perchlorate treatment pilot study will be conducted in relation to the Baldwin Park site focusing on the Aerojet bioremediation process.

Additionally, the United States Air Force at Tyndall Air Force Base, in conjunction with some perchlorate stakeholders, has also developed a different biological treatment method for perchlorate-containing wastewater. This treatment method has been bench and pilot-scale tested

for application to concentrated perchlorate wastewater streams (thousands of parts per billion). Similar to the Aerojet work, the Air Force treatment system is only known to remove perchlorate down to 400 micrograms per liter. However, this treatment process may be applicable to lower concentration perchlorate-containing water.

In addition to the pilot-scale work described above, another important study related to perchlorate is being done at the Baldwin Park Operable Unit. Region IX of the EPA has requested that a treatability study focused on perchlorate be prepared to address treatment methods other than the Aerojet biological process. A report, "Draft Technology Screening for the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin," is currently available. This report will soon be updated and finalized.

Finally, perchlorate is similar to nitrate in many respects, and treatment methods applicable to nitrate contamination might also be valuable in treatment of perchlorate contamination.

Proposal Source: Perchlorate Issue Group.

Controversial Issues:

1. There is regulatory concern about the use of biological processes that employ an external carbon source/electron donor.
2. Some of the treatment processes of interest are currently proprietary.

Audience:

- | | | | |
|---|--|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|--|--|---|
| <input type="checkbox"/> Manager | <input type="checkbox"/> Water quality | <input checked="" type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|---|---|---|--|
| <input type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input checked="" type="checkbox"/> Laboratory test | <input checked="" type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

A limited number of bioreactor systems have been successfully developed to treat water streams with high concentrations of perchlorate. Examples are the Aerojet process using a GAC/fluidized bed under anoxic conditions and the suspended growth reactor using *W.succinogens* HAP1 developed by Tyndall A.F.B. The ability of a bioreactor to reduce low concentrations of perchlorate, approximately 1,000 micrograms per liter or less to drinking water action levels of 4-18 micrograms per liter, is an important knowledge gap. Another important

knowledge gap is whether bioreactors developed for removal of nitrate (denitrification) can also be applied to removal of perchlorate.

RESEARCH APPROACH

Phase I

Bench-scale experiments should be conducted to evaluate several conditions pertinent to drinking water and low concentrations of perchlorate. Example factors to consider are:

1. Reactor type and configuration (fixed-film, continuous-flow).
2. Influent concentration of perchlorate (between 1,000 micrograms per liter and the action level (18 micrograms per liter).
3. Carbon source and nutrient requirements.
4. Identification of reaction mechanism and possible formation of reaction intermediates.
5. Determine reaction rates.
6. Operating conditions (ranges) (e.g., pH, temperature, residence time).
7. Influence of co-contaminants, including nitrate and VOCs such as trichloroethylene (TCE), perchloroethylene (PCE), etc.
8. Effect of influent dissolved oxygen on operating performance.
9. Characterization of the effluent concentrations of perchlorate, chloride, total organic carbon, heterothrophic plate count, pathogens and disinfectant byproduct formation potential, as well as establishing mass balances for the treatment process.
10. Identification of post treatment requirements, especially the need for filtration and disinfection.
11. Estimate costs and scale-up issues.

Phase II

Following completion of the bench-scale work, a separate pilot-scale project should be initiated approximately two years from now. The pilot-scale work should involve the most promising bench-scale system. Details of the pilot-scale work cannot be established at this time.

In general, the pilot-scale work should evaluate:

- Systems integration
- Scaling factors
- Process control capital & operating costs
- Operability

TITLE: TREATABILITY OF PERCHLORATE-CONTAINING WATERS BY REVERSE OSMOSIS AND NANOFILTRATION

Description of Problem: No established treatment processes have been shown to remove or reduce low perchlorate concentrations to acceptable drinking water levels. Discovery of perchlorate contamination in both ground and surface waters requires immediate identification and rapid application of an effective treatment process. Rapid implementation requires recommendation of an established water treatment process.

Objective of Research Response: To determine concentration ranges treatable by reverse osmosis and nanofiltration; to evaluate effects of water quality parameters on process performance and removal of perchlorate; to determine the limits of feedwater recovery; and characterize the waste stream and perform an investigation of concentrate treatment and disposal options.

Recommended Funding: Phase I: \$312,000 including research costs as well as AWWARF project management costs. Phase I activities will involve a literature review as well as bench-scale work. Phase II: \$513,000, including research costs as well as AWWARF project management costs. Phase II activities involve pilot-scale development work. The Phase II activities of this multi-phase study are dependent on the success of Phase I, as well as the availability of Phase II funding.

Past and Ongoing Related Research: There is a substantial knowledge base on reverse osmosis for treatment of groundwaters in terms of performance and removal of selected ions and contaminants. There has also been a substantial amount of work on nitrate removal by reverse osmosis. The behavior of nitrate and perchlorate in the environment has many similarities, so treatment of nitrate by high pressure membranes may be similar, in some respects, to treatment of perchlorate by high pressure membranes. However, there is little or no data on the removal of perchlorate by these processes.

There have been some industrial studies employing biotreatment of high concentration perchlorate waste, but none having a high concentration of salt, natural organic matter, or metallic species in addition to the perchlorate.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: None

Audience:

- | | | | |
|---|--|--|---|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input checked="" type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|--|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input checked="" type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

☐ Proof of concept ☐ Develop application ☒ Laboratory test ☒ Pilot test
☐ Full-scale test ☐ Implementation barrier ☐ Product development

BACKGROUND

Perchlorate has recently been detected in a variety of ground and surface waters within the State of California and Nevada. In some areas, perchlorate has been found in excess of the provisional action level of 18 micrograms per liter. This has resulted in the shutdown of some water supply sources. Consequently, there is substantial interest among water utilities to minimize exposure to this chemical in drinking water.

Reverse osmosis and nanofiltration are established water treatment technologies used for removal of contaminants in drinking water. Contaminants such as salts, disinfection by-product precursors, nitrates, and selected pesticides have been successfully treated by reverse osmosis and nanofiltration technology. While it is anticipated that these processes may be effective for the removal of perchlorate, there is little to no peer-reviewed data which demonstrates their applicability to this contaminant. Moreover, there is no information on the impact of background water quality matrices on the removal of perchlorate using reverse osmosis and nanofiltration.

Membrane separation processes for perchlorate removal will result in production of up to 20 percent brine. Possible co-contaminants in the concentrate require that consideration be given to volume, metal concentration, and radioactive materials in the waste stream. There may be considerable regulatory concern in disposing of the waste, including worker safety.

RESEARCH APPROACH

This research will be conducted in two phases.

As part of Phase I, the researcher would perform a literature review. This literature review should identify past and ongoing research related to the removal of chemical species similar to perchlorate, such as nitrate and bromate. As part of the review, attempts should be made to estimate the efficacy of perchlorate removal based on membrane composition and charge as well as water quality parameters.

The researcher would then conduct a bench-scale membrane screening study in order to assess:

- Applicable feedwater concentrations and achievable permeate levels.
- Impact of selected water quality parameters such as hardness, alkalinity, total organic carbon, pH, and temperature. Natural waters should be employed where possible. The researcher would determine the necessary feedwater quality to perform the membrane testing.
- Pretreatment that may be necessary, and the conditions under which pretreatment may be necessary, to decrease fouling or increase the rejection of perchlorate.
- The mechanism of removal of perchlorate.

As part of Phase I, the researcher would characterize waste production from the reverse osmosis and nanofiltration bench systems. Contaminants of concern would be identified and possible

treatment options determined. Regulatory and chemical barriers to treatment options should also be identified. Bench scale feasibility testing of possible solutions should be evaluated.

Phase II of this study will primarily focus on pilot-scale testing of promising membranes and treatment schemes. Phase II will also address treatment of the reject waters that are produced as a waste stream. In Phase II, the investigator would conduct a pilot scale study to:

1. Confirm perchlorate removal efficiencies that were determined at bench scale.
2. Optimize membrane system operational conditions.
3. Minimize generation of the waste stream.

The researcher should investigate and employ membrane system pretreatment. A minimum of one groundwater and one surface water should be employed at this scale, with these waters representing either the most difficult to treat, or the most prevalent water quality that has been impacted by perchlorate.

As part of Phase II, pilot testing of concentrate treatment methods for the raw water would be also conducted. It is expected that the reject treatment process employed would be that which was promising during Phase I.

TITLE: THE TREATABILITY OF PERCHLORATE IN GROUNDWATER USING ION EXCHANGE TECHNOLOGY

Description of Problem: A technology is needed that can reduce low concentrations of perchlorate in groundwater (1,000 micrograms per liter or less) to a concentration that is protective of human health. The technology must be reliable, cost-effective, and minimize waste. The waste must be amenable to disposal/treatment.

Objective of Research Response: To develop an optimized ion exchange process to address low concentration perchlorate contamination of groundwater. The resin, empty bed contact time, regenerant, regenerant concentration, and effluent quality with respect to potability and corrosivity should also be optimized.

Recommended Funding: Phase I - \$ 312,000 (12-18 month duration) including research costs as well as AWWARF project management costs. Phase II - \$ 256,000 to \$641,000 (18 month duration) including research costs as well as AWWARF project management costs. Phase II activities are dependent upon successful Phase I activities as well as the availability of Phase II funding.

Past and Ongoing Related Research: The treatment of perchlorate at concentrations less than 1,000 micrograms per liter is a relatively unresearched issue. A practical analytical method to detect concentrations of perchlorate less than 400 micrograms per liter has only recently been developed, accounting for this lack of research work. However, limited research has been done on the treatment of perchlorate at higher concentrations, and work is now starting on the treatment of perchlorate at lower concentrations.

Aerojet has conducted bench and pilot scale tests on a semi-proprietary biological treatment process for perchlorate at the Rancho Cordova Superfund site near Sacramento, California. These tests pre-date the development of the new analytical method, and are therefore only known to be effective to reduce perchlorate concentrations to 400 microgram per liter. A full-scale treatment plant (1,500 gallons per minute) for perchlorate treatment is currently being designed for construction and operation at this site. This biological treatment method is also being investigated in studies related to the Baldwin Park Operable Unit of the San Gabriel Superfund site for removal of perchlorate down to 4 micrograms per liter. A two-phase perchlorate treatment pilot study will be conducted in relation to the Baldwin Park site focusing on the Aerojet bioremediation process.

Additionally, the United States Air Force at Tyndall Air Force Base, in conjunction with some perchlorate stakeholders, has also developed a different biological treatment method for perchlorate-containing wastewater. This treatment method has been bench and pilot-scale tested for application to concentrated perchlorate wastewater streams (thousands of parts per billion). Similar to the Aerojet work, the Air Force treatment system is only known to remove perchlorate down to 400 micrograms per liter. However, this treatment process may be applicable to lower concentration perchlorate-containing water.

In addition to the pilot-scale work described above, another important study related to perchlorate is being done at the Baldwin Park Operable Unit. Region IX of the EPA has requested that a treatability study focused on perchlorate be prepared to address treatment methods other than the Aerojet biological process. A report, "Draft Technology Screening for the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin," is currently available. This report should be updated and finalized soon.

Finally, perchlorate is similar to nitrate in many respects, and treatment methods applicable to nitrate contamination might also be valuable in treatment of perchlorate contamination. Previous development of a nitrate ion exchange process with denitrification and reuse of spent brine may be applicable to perchlorate.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The target effluent level of 4-18 micrograms per liter is provisional. Work to support a maximum contaminate level (MCL) for drinking water is underway. The provisional level is subject to change in approximately 12 months, with a final MCL not expected for several years. There may also be intellectual property issues related to past work and use of technology.

Audience:

<input checked="" type="checkbox"/> Utilities	<input checked="" type="checkbox"/> Regulators	<input checked="" type="checkbox"/> Research Community	<input checked="" type="checkbox"/> Consultant
<input type="checkbox"/> AWWA	<input type="checkbox"/> Other Orgs.	<input type="checkbox"/> Collaborative Partners	<input checked="" type="checkbox"/> Manufacturers
<input type="checkbox"/> Congress	<input type="checkbox"/> Education	<input type="checkbox"/> Environmental Groups	<input type="checkbox"/> AWWARF (internal)

Utility Audience:

<input type="checkbox"/> Manager	<input checked="" type="checkbox"/> Water quality	<input checked="" type="checkbox"/> Design and engineering	<input type="checkbox"/> Administration
<input type="checkbox"/> Public affairs	<input type="checkbox"/> Operations	<input type="checkbox"/> Other _____	

Position on Research Continuum:

<input type="checkbox"/> Proof of concept	<input type="checkbox"/> Develop application	<input checked="" type="checkbox"/> Laboratory test	<input checked="" type="checkbox"/> Pilot test
<input type="checkbox"/> Full-scale test	<input type="checkbox"/> Implementation barrier	<input type="checkbox"/> Product development	

BACKGROUND

In a recent Aerojet study addressing perchlorate contamination at their Rancho Cordova site, Aerojet started with a screening of available treatment technologies. From this screening ion exchange technology seemed the most viable for effective treatment of large quantities of contaminated water. Aerojet then devoted considerable effort to develop an ion exchange treatment system for perchlorate contamination. However, the Aerojet work ended with the development of a biological treatment process. Difficulties that were encountered in the development of an ion exchange treatment process included the following.

1. Perchlorate has a high affinity for ion-exchange resins.
2. The high affinity of perchlorate for resins leads to difficulty in regeneration.

3. An optimum resin for perchlorate has not been selected.
4. Competition with other anions and the position of perchlorate in a selectivity sequence has not been determined.
5. Regeneration of the resin, resin lifetime, and resin disposal are key issues to resolve.
6. A nitrate ion exchange process with brine denitrification and reuse has been developed and may be modified to satisfy project objectives.

RESEARCH APPROACH

This research will be conducted in two phases, with the second phase being a larger-scale pilot testing program.

As part of Phase I, the researcher would perform a literature review. This literature review should identify past and ongoing ion exchange research related to the removal of perchlorate, or chemicals similar to perchlorate, such as nitrate and bromate. As part of the review, attempts should be made to identify ion exchange resin characteristics of interest. If possible, these characteristics should be cross-referenced to expected water quality parameters of interest.

Phase I

1. Establish the composition of the test water (synthetic groundwater).
2. Select representative resins from available strong and weak base resins.
3. Screen representative resins using column tests. Measure adsorption and regeneration for at least five cycles. Choose regenerant and concentration.
4. Perform bench-scale testing to establish optimum empty bed contact time, quality of the effluent, and quality of the spent regenerant. Establish effect of water quality parameters including nitrate and sulfate concentrations. Perform test on an actual groundwater, spiking with perchlorate, sulfate, nitrate, volatile organic compounds or other contaminants to simulate natural water quality.
5. Establish conditions for biological degradation of perchlorate in regenerant. Determine suitability of regenerant for reuse.
6. Combine ion-exchange and biological degradation components in a single bench-scale system. Run for a minimum of 15 cycles.
7. Design a pilot-scale system to verify bench-scale results. Provide preliminary cost estimate for scale-up to demonstration scale system.

Phase II of this study will primarily focus on pilot-scale testing of promising ion exchange treatment schemes. These treatment schemes will be tested on two to three pilot-scale groundwaters from actual water supplies. Phase II will also address treatment of the waste stream.

Phase II

1. Confirm perchlorate removal efficiencies that were determined at bench scale.
2. Optimize system operational conditions.
3. Minimize generation of the waste stream and characterize this waste stream.

TITLE: SURVEY THE PERFORMANCE OF THE CALIFORNIA DHS (ION CHROMATOGRAPHY) ANALYTICAL PROTOCOL

Description of Problem: Important water supply decisions are being made on the basis of perchlorate analytical results from laboratories following the California Department of Health Services (CDHS) ion chromatography analytical protocol. Numerous inter-lab and intra-lab QA procedures have been performed, but have not been gathered into a single document for evaluation of the methodology.

Objective of Research Response: This research will bring together all available information on the performance of the CDHS perchlorate method and evaluate the method for analysis of low concentrations of perchlorate in surface water and groundwater samples. The document will be used for formal method approval as well as further method development.

Recommended Funding: Total funding of \$94,000, including both research costs as well as AWWARF project management costs. This project should be completed with two years.

Past and Ongoing Related Research: The new ion chromatography method for analysis of the perchlorate ion was developed by the CDHS in 1997. Therefore, there is relatively little research information available in the literature regarding this method. The CDHS should be contacted for information and data related to development of this new method, as well as for the method protocol. Similarly, the CDHS has an approval process for commercial laboratories that are doing perchlorate analyses. The approval process, as well as the data submitted by the commercial laboratories, is potentially relevant information to this study. The EPA is currently doing an evaluation study of the CDHS ion chromatography method and should be contacted for relevant information. The United States Air Force (USAF) is also conducting a peer review study of the new CDHS ion chromatography method and should also be contacted for information. With the exception of the CDHS ion chromatography protocol, all of the above studies are ongoing with no published results to date.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The method must be acceptable to the EPA, state agencies, and the appropriate Standard Methods committee.

Audience:

- | | | | |
|---|--|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|--|---|---|-------------------------------------|
| <input checked="" type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input checked="" type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

CDHS developed an enhanced ion chromatographic method for the analysis of low concentrations of perchlorate (4 micrograms per liter) in April 1997. Since then at least six commercial laboratories in California, four public agency labs and several private and commercial labs outside of California have developed this analytical capability. Several evaluations of the method and performance of various laboratories have been sponsored by the EPA, USAF, CDHS, Nevada Division of Environmental Protection, Metropolitan Water District of Southern California, Southern Nevada Water Authority, and others. The available performance information from the commercial laboratories as well as from the method evaluations needs to be brought together in a single informative document.

Eventual publication of an official analytical protocol as well as widespread acceptance of the method requires a thorough evaluation of the method's performance on a wide range of environmental and water supply samples.

RESEARCH APPROACH

This project would be a short-term, high priority study of what is already known regarding the analysis of perchlorate in environmental media. This project would involve gathering available laboratory performance data (inter-lab and intra-lab QA/QC data) into a single document. These data, and the lessons learned relative to analysis for perchlorate, would be summarized in the final document. This final document will prove useful in evaluating information pertinent to performance of the method, identifying apparent difficulties due to factors such as water quality, possible interferences, or high or low perchlorate concentration effects.

The initial steps for information gathering relative to this project would involve contacting the EPA, USAF, CDHS, Nevada Division of Environmental Protection, Metropolitan Water District of Southern California, Southern Nevada Water Authority, California-approved laboratories, Kerr-McGee, Montgomery-Watson and other non-California labs for helpful and useful method information (i.e., clean-up procedures, matrix effects, etc.).

Laboratory performance data would include results of split and duplicate samples, detection limits on field samples, method modifications or clarifications developed by the laboratories, results on performance evaluation samples or other multi-laboratory determinations, effects introduced by holding time or matrix differences, possible correlations of conductivity, nitrate, sulfate, surfactants, or other anions on method performance.

The final document would be a comprehensive report that brings together all available information on the performance of the CDHS perchlorate method. This report should be formatted in anticipation of its use for formal method approval through a peer review process as well as further method development.

TITLE: SHORT-TERM PERCHLORATE LABORATORY ISSUES

Description of Problem: The California Department of Health Services (CDHS) recently developed a new, draft method for the analysis of perchlorate in water matrices. The method is based upon ion chromatography with conductivity detection. This method has a reported quantification limit of 4 micrograms per liter. Although this method appears to meet scientific requirements, some laboratory-based studies are needed to answer CDHS method performance questions. The answers are needed to finalize the draft method and to validate it for regulatory purposes.

Objective of Research Response: Develop an "interim method" with expanded Quality Assurance/Quality Control (QA/QC) for the purpose of widespread distribution and future inter-laboratory study.

Recommended Funding: Total funding of \$125,000, including both research costs as well as AWWARF administrative costs. This project should be completed within one year.

Past and Ongoing Related Research: The new ion chromatography method for analysis of the perchlorate ion was developed by the CDHS in 1997. Therefore, there is relatively little research information available in the literature regarding this method. The CDHS should be contacted for information and data related to development of this new method, as well as for the method protocol. Similarly, the CDHS has an approval process for commercial laboratories that are doing perchlorate analyses. The approval process, as well as the data submitted by the commercial laboratories, is potentially relevant information to this study. The EPA is currently doing an evaluation study of the CDHS ion chromatography method and should be contacted for relevant information. The United States Air Force (USAF) is also conducting a peer review study of the new CDHS ion chromatography method and should also be contacted for relevant information. With the exception of the CDHS ion chromatography protocol, all of the above studies are ongoing with no published results to date.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: None

Audience:

- | | | | |
|---|--|---|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input checked="" type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|---|--|--|-------------------------------------|
| <input type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input checked="" type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

CDHS developed an enhanced ion chromatographic method for the analysis of low concentrations of perchlorate (4 micrograms per liter) in April 1997. Since then at least six commercial laboratories in California, four public agency labs and several private and commercial labs outside of California have developed this analytical capability. Several evaluations of the method and performance of various laboratories have been sponsored by the EPA, USAF, CDHS, Nevada Division of Environmental Protection, Metropolitan Water District of Southern California, Southern Nevada Water Authority, and others.

The experiments anticipated in this project would provide answers about method features and the level of performance of the CDHS ion chromatography method. This information will be of interest to regulatory and utility users.

RESEARCH APPROACH

Prepare an experimental design, conduct lab tests, and assess results. The results of this work would be submitted in a final report. Topics of this study would include:

- Determine separations achieved from the perchlorate peak by potentially interfering anions;
- Determine appropriate sample holding time limits, degree of adsorption of perchlorate on surfaces of vessels and equipment, need for sample preservation, and procedures for sample storage;
- Investigate sample cleanup and pre-concentration procedures to improve detection limits and method reliability on environmental aqueous matrices;
- Verify the effectiveness of dilution, spiking, and fortification procedures that are being used for difficult samples and for verification of method accuracy; and
- Verify that the method is perchlorate-specific for field samples by developing a research-grade procedure for validating results obtained by the primary CDHS method.

This information would be summarized in a final document that could be used by laboratories doing perchlorate analyses. This final document should be formatted in such a manner that it interfaces well with the current CDHS protocol.

TITLE: REMOVAL OF PERCHLORATE AND BROMATE IN CONVENTIONAL OZONE/GAC SYSTEMS

Description of Problem: A technology is needed that can reduce low concentrations of perchlorate in water (1,000 micrograms per liter or less) to a concentration that is protective of human health. The technology must be reliable, cost-effective, and minimize waste. Groundwater and surface water treatment systems commonly use ozone (or ozone plus hydrogen peroxide) followed granular activated carbon (GAC) as a treatment process. There are preliminary data that indicate successful perchlorate removal in these ozone/GAC treatment systems. This research will further explore the potential viability of an ozone/GAC treatment process for perchlorate removal.

Objectives of Research: The goal of this research is to determine whether the conventional ozone/GAC process can be operated in a manner that will accomplish the removal of perchlorate. Perchlorate removal should be done without interfering with the system performance for its other functions, such as chemical oxidation of contaminants, disinfection, biological stabilization and adsorption. Because the conditions required for bromate removal may be similar to those required for perchlorate removal, bromate removal should also be investigated. Specific objectives are to determine: whether perchlorate and bromate are removed by the chemical reactions associated with the application of the oxidant and its reactions with activated carbon; to determine whether the ozone/GAC process can be modified so that perchlorate and bromate can be removed by chemical means; and, to determine whether the process can be modified to remove perchlorate and bromate biologically.

Recommended Funding: Phase I: \$188,000, including research costs and AWWARF project management costs. Phase I activities will investigate the chemical reactions and initiate biological studies. Phase I will last one year. Phase II: \$577,000, including research costs and AWWARF project management costs. Phase II activities will complete the biological studies and conduct pilot-scale testing to demonstrate the process and determine design and operating parameters. Phase II activities are expected to last up to two years. The Phase II activities of this multi-phase study are dependent upon the success of Phase I activities as well as the availability of Phase II funding.

Past and Ongoing Related Research: Previous studies have shown that oxidants will react with activated carbon. Reactions that do not take place in the bulk solution, such as polymerization of adsorbed organic compounds, can then occur. Activated carbon is also a well-known reducing agent for substances such as aqueous chlorine, which it rapidly converts to chloride. Activated carbon may also provide a pathway for rapid reduction of perchlorate and bromate to chloride and bromide, respectively.

The research of van der Kooij et al. has shown that bromate can be biologically reduced to bromide, and other studies have shown that biological treatment can be used to remove perchlorate. However, this research has not shown how an operating ozone/GAC system would have to be operated to remove perchlorate and bromate. Similarly, the design parameters used for the system (GAC empty bed contact time in particular) may need to be modified to result in good removal of perchlorate and bromide ions.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: None

Audience:

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|---|--|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|--|---|--|-------------------------------------|
| <input checked="" type="checkbox"/> Proof of concept | <input checked="" type="checkbox"/> Develop application | <input type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

Perchlorate and bromate are thermodynamically unstable in water. However, their activation energies for reaction with water to produce chloride and bromide, respectively, are very high. Therefore, their reaction rates at ambient conditions and in dilute solutions, are negligible. However, the presence of a catalyst can speed up these reactions. Such a catalyst may be either inorganic or biological. The chloride in perchlorate is at its highest oxidation state, so there is no possibility of removing perchlorate by oxidizing it. The best option for destroying both perchlorate and bromate appears to be to use them as electron acceptors, and thus to reduce them to other forms, such as chloride and bromide, respectively. Activated carbon is a reduced form of carbon that can supply electrons for reduction processes, but research is needed to determine the best way to condition the activated carbon surface so that the desired chemical reactions can take place. Research is also needed to demonstrate that the activated carbon surface is not fouled by natural organic matter. Studies should be done to determine whether removal of perchlorate and bromate can occur by this means.

RESEARCH APPROACH

Ozonation prior to GAC treatment generally increases the amount of biological activity in the adsorber (GAC) by converting a portion of the natural organic matter into biodegradable compounds. Research is needed to determine if the biological activity can remove bromate and perchlorate. Critical questions related to the biological reduction of bromate and perchlorate include: 1) is it possible to develop a biofilm that will result in the removal of both chemicals in a reasonable time, 2) what are the procedures and time required to develop the biofilm, 3) what are the chemical concentrations that must be maintained and operating procedures that must be used to maintain the biofilm, and 4) are any of the other functions (disinfection, adsorption, biological stabilization) of the ozone/GAC processes impeded if it is also used for removal of these species?

Phase I: Bench scale studies would be used to determine whether removal will occur and, if so, under what water quality conditions. There seems to be multiple roles activated carbon can take in the reduction of perchlorate. Activated carbon can either supply electrons for reduction processes from the reduced form of carbon, or facilitate the development of a biofilm that can enhance biological reduction of perchlorate. For these reasons, Phase I activities would include a preliminary assessment of the ability of fresh or virgin GAC (with and without preozonation) to reduce perchlorate. The researcher may also explore the ability of other reduced surfaces, e.g., iron, etc., to supply electrons for reduction processes. Top priority must be given to experiments that show that the desired removals can be achieved without adding inorganic or organic substances. The addition of inorganic or organic substances could promote biological growth in the distribution system, introduce undesirable tastes and odors to the water, or cause other adverse effects. Special emphasis should be given to determining whether sufficient electron donors will be available after ozonation of natural water so that the addition of a substance such as ethanol for this purpose can be avoided. The presence of ammonia and resulting nitrification may help to create sufficient reducing conditions for treatment of bromate and perchlorate. Under certain water quality conditions ozonation may result in by-products (e.g., peroxide, in aqueous electrons) that donate electrons sufficiently to facilitate the production of selected ozone by-products that can contribute to perchlorate reduction. These reactions should be explored as a part of Phase I activities.

Phase II: Promising approaches to reducing perchlorate would be investigated in detail. The process needs to be refined at the bench scale, and a pilot study would be needed to show that the process will work at a larger scale. The pilot scale conditions should be representative of those encountered in field operations. The goal of this research will be to develop design data and operating procedures to accomplish the desired removals. Successful pilot scale work should also include characterization of the GAC biofilm itself. Such issues as the distribution of the biofilm, type of dominant bacteria (aerobic, facultative, anaerobic) and sensitivity to water quality changes should be investigated.

TITLE: INVESTIGATION OF METHODS FOR PERCHLORATE DESTRUCTION IN AQUEOUS WASTE STREAMS

Description of Problem: To date, the only demonstrated method available for perchlorate destruction is biological reduction. Discovery of perchlorate contamination in both ground and surface waters requires immediate identification and rapid application of effective treatment processes. Most treatment processes, except possibly biological processes, will involve production of a waste stream concentrated in perchlorate that must be addressed.

Objective of Research Response: Evaluate non-biological technologies for destruction of perchlorate to allow waste stream disposal or recycle.

Recommended Funding: Total funding of \$827,000 over two phases, including research costs as well as AWWARF research management costs. Phase I will consist of two studies at \$125,000 each for a total of \$250,000. Phase II will consist of \$577,000 for a pilot-scale study of one selected technology. Phase II activities are dependent upon the success of Phase I activities as well as the availability of Phase II funding.

Past and Ongoing Related Research: The treatment of perchlorate at concentrations less than 1,000 micrograms per liter is a new issue with little previous research. However, Aerojet and the United States Air Force at Tyndall Air Force Base have conducted research on the treatment of perchlorate at higher concentrations. Both of these studies addressed the treatment of perchlorate contamination at higher concentrations, thousands of micrograms per liter or greater, as might be expected from treatment processes applied to low concentration perchlorate contamination. The Aerojet study started with a screening of treatment technologies, and devoted considerable development effort to ion exchange treatment of perchlorate. However, the Aerojet work and the Air Force work both ended with the development of a biological treatment process. These biological treatment processes are not identical. In addition, a screening of treatment technologies to address low concentrations of perchlorate contamination in groundwater is currently being conducted for the Region IX EPA. A report, "Draft Technology Screening for the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin," which is expected to be updated soon, is available. Also, perchlorate is similar to nitrate in many respects, and treatment methods applicable to nitrate contamination might also be valuable in treatment of perchlorate contamination.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: None

Audience:

- | | | | |
|---|--|---|---|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input type="checkbox"/> Research Community | <input checked="" type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input checked="" type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

☐ Manager ☒ Water quality ☐ Design and engineering ☐ Administration
☐ Public affairs ☒ Operations ☐ Other _____

Position on Research Continuum:

☒ Proof of concept ☐ Develop application ☒ Laboratory test ☒ Pilot test
☐ Full-scale test ☐ Implementation barrier ☐ Product development

BACKGROUND

A number of processes are available for perchlorate removal from drinking water. Many of these processes, e.g., ion exchange, membranes, etc., are likely to produce concentrated waste streams containing perchlorate. A means of dealing with the concentrated perchlorate stream is needed in order to implement the primary processes.

RESEARCH APPROACH

Research would be done in two phases. Phase I would for \$256,000 total with individual proposals limited to \$128,000 each. Bench or laboratory scale would be acceptable. The researcher should demonstrate:

- Concentration viability range to safe acceptable levels for disposal or recycle.
- Determine impact of waste quality parameters on process, e.g. nitrate (NO_3), total dissolved solids (TDS), trichloroethylene (TCE), natural organic matter (NOM), etc.
- Characterize process by-products.
- Determine Chloride mass balance.

Decision would be made at the end of Phase I to determine whether or not to proceed to Phase II.

Phase II would be for \$577,000 to be conducted as a pilot-scale on a variety of waste sources.

The researcher must demonstrate:

- Process at higher flow rate
- Cost effectiveness and reliability
- Operational and maintenance issues
- Treatability of other contaminants (e.g., NO_3 , TCE, TDS, NOM, etc.)
- Efficiency of process
- Secondary waste disposal/treatment
- Engineering safety of the process

The researcher must evaluate further scale-up issues for a demonstration scale unit and prepare a conceptual preliminary design for a full-scale unit.

TITLE: ASSESSMENT OF ENZYME BASED REACTOR SYSTEMS ON PERCHLORATE REDUCTION

Description of Problem: There is no effective treatment technology for removal, destruction, or reduction of perchlorate in drinking water supplies.

Objective of Research Response: Isolate enzyme(s) selective for reduction of perchlorate to chloride. Demonstrate ability to express enzyme(s) in production quantities. Demonstrate efficacy of enzymes in conventional reactor systems for reducing perchlorate concentrations of up to 1,000 micrograms per liter to below the action level of 18 micrograms per liter.

Recommended Funding: \$385,000 24 months (Phase I) \$1,090,000 24 months (Phase II), which includes research costs as well as AWWARF administrative costs. The Phase II activities of this multi-phase study are dependent on the success of Phase I activities, as well as the availability of Phase II funding.

Past and Ongoing Related Research: Aerojet has conducted bench and pilot scale tests on a semi-proprietary biological treatment process for perchlorate at the Rancho Cordova Superfund site near Sacramento, California. This biological treatment method is also being investigated in studies related to the Baldwin Park Operable Unit of the San Gabriel Superfund site for removal of perchlorate down to 4 micrograms per liter. A two-phase perchlorate treatment pilot study will be conducted in relation to the Baldwin Park site focusing on the Aerojet bioremediation process.

Additionally, the United States Air Force at Tyndall Air Force Base, in conjunction with some perchlorate stakeholders, has also developed a different biological treatment method for perchlorate-containing wastewater using *W. succinogenes* HAP1. This treatment method has been bench and pilot-scale tested for application to concentrated perchlorate wastewater streams (thousands of parts per billion). Similar to the Aerojet work, the Air Force treatment system is only known to remove perchlorate down to 400 micrograms per liter. However, this treatment process may be applicable to lower concentration perchlorate-containing water.

Finally, perchlorate is similar to nitrate in many respects, and biological treatment methods applicable to nitrate contamination might also be valuable in identifying enzymes with potential application to the treatment of perchlorate contamination.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: Limited success in some enzyme extraction. Very high impact if successful.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada,

approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

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|---|--|---|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|--|---|---|-------------------------------------|
| <input checked="" type="checkbox"/> Proof of concept | <input checked="" type="checkbox"/> Develop application | <input checked="" type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

Enzyme expression and isolation is a technology that has already been applied to the treatment of nitrate, a contaminant that is similar in many ways to perchlorate. However, this project is anticipated to build upon the existing Aerojet perchlorate treatment process as well as the USAF perchlorate treatment process.

RESEARCH APPROACH

Phase I

Bench-scale isolation and purification of perchlorate, chlorate, and chlorite enzymes. Immobilize enzymes into thin surface matrices using appropriate electron source (e.g., low voltage electricity). Reduce immobilized enzymes. Demonstrate that the reduced enzymes transfer electrons to substrate, converting perchlorate or chlorate to chloride and molecular oxygen. Demonstrate that enzymes can be arranged in conventional reactor configurations and reduce perchlorate from less than 1,000 micrograms per liter to below the action level. Based on the results of this work, estimate pilot-scale capital/operating costs.

Phase II

Upon successful completion of Phase I (bench-scale) a pilot-scale system will be designed and constructed to address the following issues: 1) Systems integration, 2) Engineering scaling factors, 3) Process automation and control, 4) Preliminary life-cycle cost estimate, and 5) Process operability.

Process scale should be chosen to ensure that the pilot-scale data will provide the basis for full-scale system design.

TITLE: LITERATURE/EXPERT PANEL REVIEW FOR EFFECTIVE IN-SITU TREATMENT AND CONTAINMENT TECHNOLOGIES FOR PERCHLORATE IN SOIL AND GROUNDWATER

Description of Problem: Currently, the primary focus for the removal of perchlorate is pump and treat at the water delivery point source (well head/intake). This study will define in-situ treatment methods that could potentially protect the well before it is contaminated by perchlorate, thus eliminating or significantly reducing the need for well head treatment by the water utility.

Objective of Research Response: To assemble a database of theoretical and applied research results on in-situ soil and groundwater perchlorate remediation and containment. This database will be used to identify additional needed research, if any, to make in-situ treatment and containment of perchlorate more technically viable. The final report will identify tools and past experiences useful for evaluation of in-situ treatment and containment of perchlorate contamination.

Recommended Funding: \$64,000, which includes research costs as well as AWWARF administrative costs.

Past and Ongoing Related Research: Presently unknown. The objective of this study is to determine what related research has been conducted and to use that information to develop recommendations for further research topics.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: If the recommendations for further research involve the introduction of foreign material into an aquifer, such as perchlorate or tracer compounds, this will raise concerns of regulatory bodies and in general public.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

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|---|--|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input checked="" type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

☒ Proof of concept ☒ Develop application ☐ Laboratory test ☐ Pilot test
☐ Full-scale test ☐ Implementation barrier ☐ Product development

BACKGROUND

Perchlorate has recently been detected in a variety of groundwater and surface water sources. The concentration of perchlorate in some of these waters has exceeded the provisional action level of 18 micrograms per liter established by the California Department of Health Services (CDHS). In most instances perchlorate has been found as a contaminant of groundwater. The application of in-situ treatment and containment technologies might significantly reduce the numbers of wells at which perchlorate treatment will come to be necessary. In-situ treatment for many other contaminants has proven to be more cost effective than pump-and-treat technologies.

RESEARCH APPROACH

The researchers would conduct a literature review on past and ongoing research related to this subject. While it is expected that relatively little information will be found related to in-situ treatment or containment of perchlorate, information will be found on similar contaminants such as nitrate. The lessons learned from other contaminants might be readily adaptable to perchlorate contamination.

The researchers should have expertise in biological and/or chemical reduction processes. The researcher will include applied or theoretical applications of in-situ treatment technologies for the reduction of perchlorate or chemicals of similar composition. A database of findings will be compiled that addresses the following criteria:

- Broad applicability under variable site conditions
- Water quality parameters affecting potability
- Application over a broad concentration range
- Cost effectiveness
- Effectiveness on other contaminants, i.e., volatile organic compounds (VOCs), metals
- Successful field applications

The results of the database search will be used to rank the applicable technologies. The ranking criteria will include, but not be limited to: broad applicability under variable site conditions; water quality parameters affecting potability; application over a broad concentration range; cost effectiveness; effectiveness on other contaminants; and successful field applications. This ranked database will ultimately result in recommendations for expanded research into viable applications for in-situ treatment technologies for soil and groundwater contaminated with perchlorate. In addition, some of the barriers to in-situ treatment or containment (such as requirements for demonstration of adequate treatment, or Environmental Assessment requirements) will also be identified and addressed in the final document. The identification of these barriers and the tools to address them will likely make full-scale implementation of in-situ technologies more successful. Based on this ranking the researcher/panel will make

recommendations for expanded research into viable in-situ treatment technologies for soil and groundwater contaminated with perchlorate.

TITLE: DEMONSTRATION OF ELECTRODIALYSIS AND ELECTRODIALYSIS REVERSAL AS A CONTROL TECHNOLOGY FOR PERCHLORATE-CONTAINING WATERS

Description of Problem: No established treatment processes have been shown to remove or reduce perchlorate concentrations to acceptable drinking water levels. Discovery of perchlorate contamination in both ground and surface waters requires immediate identification and rapid application of an effective treatment process. Rapid implementation requires recommendation of an established water treatment process.

Objective of Research Response: To determine concentration ranges treatable by electrodialysis and electrodialysis reversal; to evaluate the effect of water quality parameters on process performance and the removal of perchlorate; and to determine the limits of brine production.

Recommended Funding: \$577,000 which includes research costs as well as AWWARF administrative costs.

Past and Ongoing Related Research: There is a substantial knowledge base on electrodialysis and electrodialysis reversal for groundwaters in terms of performance and removal of selected ions and contaminants. However, there is little to no data on the removal of perchlorate by these processes, nor on the impact of background water quality matrices on removal of perchlorate.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The first controversial issue is that perchlorate contamination in the environment is seen by many as a California-specific issue. The second controversial issue is that there are no known enforceable regulations that address perchlorate contamination of drinking water in any state. Similarly, the EPA does not have an enforceable standard for this contaminant.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

<input checked="" type="checkbox"/> Utilities	<input checked="" type="checkbox"/> Regulators	<input checked="" type="checkbox"/> Research Community	<input checked="" type="checkbox"/> Consultant
<input checked="" type="checkbox"/> AWWA	<input type="checkbox"/> Other Orgs.	<input type="checkbox"/> Collaborative Partners	<input type="checkbox"/> Manufacturers
<input type="checkbox"/> Congress	<input type="checkbox"/> Education	<input type="checkbox"/> Environmental Groups	<input type="checkbox"/> AWWARF (internal)

Utility Audience:

☐ Manager ☒ **Water quality** ☐ Design and engineering ☐ Administration
☐ Public affairs ☐ Operations ☐ Other _____

Position on Research Continuum:

☒ Proof of concept ☒ Develop application ☒ Laboratory test ☒ Pilot test
☐ Full-scale test ☐ Implementation barrier ☐ Product development

BACKGROUND

Perchlorate has been recently detected in a variety of ground and surface waters at levels near or exceeding provisional action levels. This has resulted, in some cases, in the shutdown of water supply sources. Consequently, there is substantial interest among water utilities to minimize exposure to this chemical in drinking water.

Electrodialysis and electrodialysis reversal are established water treatment technologies used for removal of a variety of inorganic contaminants in drinking water. While it is anticipated that these processes may be effective for the removal of perchlorate, there is little to no peer-reviewed data which demonstrate their applicability to treatment of this contaminant. Moreover, there is no information on the impact of background water quality matrices on the removal of this compound.

RESEARCH APPROACH

At the start of this study, a literature review will be done. This literature review will focus on the removal of chemical species similar to perchlorate, such as nitrate and bromate. As part of the review, the efficacy of perchlorate removal by these technologies under various water quality conditions should be estimated. The investigator would then conduct a bench-scale study to optimize removal capabilities and minimize waste stream generation. Pretreatment should be employed as necessary. A minimum of one groundwater and one surface water should be employed during the pilot testing.

The researcher would also characterize waste production from the electrodialysis and electrodialysis reversal systems. Contaminants of concern would be identified and possible treatment options determined. Both regulatory and chemical barriers to treatment options should also be identified.

The investigator would conduct a pilot scale study to:

1. Assess perchlorate removal efficiency by electrodialysis and electrodialysis reversal.
2. Optimize system operational conditions.
3. Minimize generation of the waste stream.
4. Generate scale-up information, if possible, for field application of this process to perchlorate contamination.

5. At the conclusion of the study, the researchers should prepare reconnaissance level cost estimates for the process (capital, operations and maintenance, and total cost).

The results of this work would be summarized in a final report. This final report should identify optimized operational conditions as well as the design considerations for full-scale application of this treatment process. Additional research needs should be addressed as well.

TITLE: INVESTIGATION OF INNOVATIVE TECHNOLOGIES FOR PERCHLORATE REMOVAL FROM DRINKING WATER SOURCES

Description of Problem: No established treatment processes have been shown to remove or reduce perchlorate in drinking water. Prompt investigation of innovative technologies is needed by the water industry.

Objective of Research Response: Evaluate up to three innovative technologies (or synthesis of existing six known technologies) for removal of perchlorate to safe acceptable levels (currently at 4 to 18 micrograms per liter). One technology may be further investigated for potential applicability.

Recommended Funding: Total budget is \$962,000, including research costs as well as AWWARF administrative costs. This will be a two phase project. Phase I will have a total budget of \$385,000 and up to three technologies at \$128,000 each will be funded. Depending on success of Phase I, and the availability of Phase II funding, one technology may be further evaluated at the pilot-scale with a budget of \$577,000.

Past and Ongoing Related Research: The treatment of perchlorate at concentrations less than 1,000 micrograms per liter is a relatively unresearched issue. A practical analytical method to detect concentrations of perchlorate less than 400 micrograms per liter has only recently been developed, accounting for this lack of research work. However, limited research has been done on the treatment of perchlorate at higher concentrations, and work is now starting on the treatment of perchlorate at lower concentrations.

Aerojet has conducted bench and pilot scale tests on a semi-proprietary biological treatment process for perchlorate at the Rancho Cordova Superfund site near Sacramento, California. These tests pre-date the development of the new analytical method, and are therefore only known to be effective to reduce perchlorate concentrations to 400 microgram per liter. A full-scale plant (1,500 gallons per minute) for perchlorate treatment is currently being designed at this site. This biological treatment method is also being investigated in studies related to the Baldwin Park Operable Unit of the San Gabriel Superfund site for removal of perchlorate down to 4 micrograms per liter. A two-phase perchlorate treatment pilot study will be conducted in relation to the Baldwin Park site focusing on the Aerojet bioremediation process.

Additionally, the United States Air Force at Tyndall Air Force Base, in conjunction with some perchlorate stakeholders, has also developed a different biological treatment method for perchlorate-containing wastewater. This treatment method has been bench and pilot-scale tested for application to concentrated perchlorate wastewater streams (thousands of parts per billion). Similar to the Aerojet work, the Air Force treatment system is only known to remove perchlorate down to 400 micrograms per liter. However, this treatment process may be applicable to lower concentration perchlorate-containing water.

In addition to the pilot-scale work described above, another important study related to perchlorate is being done at the Baldwin Park Operable Unit. Region IX of the EPA has

requested that a treatability study focused on perchlorate be prepared to address treatment methods other than the Aerojet biological process. A report, "Draft Technology Screening for the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin," is currently available. This report should be updated soon.

Finally, perchlorate is similar to nitrate in many respects, and treatment methods applicable to nitrate contamination might also be valuable in treatment of perchlorate contamination.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: Some of the processes to be investigated be proprietary or patented. This may present significant contracting difficulties since AWWARF will not fund a project that will benefit any commercial concern over others.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

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|---|--|--|---|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input checked="" type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input checked="" type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|--|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input checked="" type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|--|---|---|--|
| <input checked="" type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input checked="" type="checkbox"/> Laboratory test | <input checked="" type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

Currently, there are three general treatment processes for the removal of perchlorate from water that are actively being explored. These include biologically based reactors, ion exchange, and membrane processes (e.g., RO/NF, ED). There is a need to systematically explore new treatment technologies that are capable of removing perchlorate to safe levels without significant waste stream generation, significant site specific treatability limitations, and other concerns noted for the more established treatment methods.

RESEARCH APPROACH

Research is to be done in two phases.

Phase I: \$385,000 total. Projects limited to \$128,000 each, with AWWARF reserving the right to fund one to three (or none) of the proposals.

Bench- or laboratory-scale work for Phase I are both acceptable. The researcher should:

- Demonstrate concentration viability range to safe acceptable levels for potable water production.
- Determine impact of water quality parameters on processes; i.e. use real water. Parameters may include trichloroethylene (TCE), nitrate, natural organic matter (NOM), total dissolved solids (TDS), etc.
- Characterize the waste stream.
- Determine mass balance of chlorite.

The decision will be made at the end of Phase I on whether to proceed to Phase II. One technology may be selected for further investigation.

Phase II: \$577,000 total.

Phase II work will be conducted at a pilot-scale level that allows for scale-up to full-scale. Depending on the chosen technology, the PAC may require evaluating the chosen technology on more than one water source. The research team must:

- Demonstrate process at higher throughput.
- Demonstrate reliability of the process.
- Evaluate treatability of other contaminants likely present (e.g., nitrate, TCE, NOM, TDS, as appropriate).
- Investigate operational and maintenance (O & M) issues.
- Evaluate waste production, disposal, and treatability issues (water balance).
- Determine engineering safety of the process.
- Conduct preliminary evaluation of further scale up issues (i.e., demonstration-scale to full-scale).
- Prepare preliminary concept design.
- Determine capital and O & M cost for full scale operations.

If additional dollars are available, additional water sources should be evaluated.

TITLE: DEVELOPMENT OF AN ALTERNATIVE ANALYTICAL METHOD FOR MEASURING PERCHLORATE ION AT THE 4 MICROGRAMS PER LITER LEVEL

Description of Problem: A single ion chromatography (IC) method exists for perchlorate measurement. A second method capable of measuring at the 4 micrograms per liter level is required for verifying low level concentrations in field samples.

Objective of the Research Response: Develop a low level perchlorate method (4 micrograms per liter detection limit or lower) applicable to groundwater and surface water field samples. This method should be easily transferable to a water utility. This procedure will be used to verify the existence and concentration of perchlorate in environmental samples.

Recommended Funding: \$160,000, which includes research costs as well as AWWARF administrative costs.

Past and Ongoing Related Research: The new ion chromatography method for analysis of the perchlorate ion was developed by the California Department of Health Services (CDHS) in 1997. Therefore, there is relatively little research information available in the literature regarding this method. The CDHS should be contacted for information and data related to development of this new method, as well as for the method protocol. The EPA is currently doing an evaluation study of the CDHS ion chromatography method and should be contacted for relevant information. The United States Air Force (USAF) is also conducting a peer review study of the new CDHS IC method and should also be contacted for relevant information. With the exception of the CDHS IC protocol, all of the above studies are ongoing with no published results to date.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The first controversial issue is that perchlorate contamination in the environment is seen by many as a California-specific issue. The second controversial issue is that there are no known enforceable regulations that address perchlorate contamination of drinking water in any state. Similarly, the EPA does not have an enforceable standard for this contaminant.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

- | | | | |
|---|--|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

☐ Manager ☒ Water quality ☐ Design and engineering ☐ Administration
☐ Public affairs ☐ Operations ☐ Other _____

Position on Research Continuum:

☐ Proof of concept ☐ Develop application ☒ Laboratory test ☐ Pilot test
☐ Full-scale test ☐ Implementation barrier ☐ Product development

BACKGROUND

Perchlorate has been detected in groundwater and surface water. The source is believed to be related to the manufacture and use of solid rocket propellants. The EPA (and the CDHS) has set a preliminary action level at 4 - 18 micrograms per liter of perchlorate. The current ion chromatography method has the capability of measuring 4 micrograms per liter. Because water quality in which perchlorate can be found differs, a second analytical method is sought to verify concentration of field samples.

RESEARCH APPROACH

The developed method is required to measure at the 4 micrograms per liter level. The precision at the 4 micrograms per liter level should be $\pm 20\%$. QA/QC documentation as specific for EPA acceptable methods are required.

The method to be developed should be based on a different principle than IC or a selective detection method to analyze perchlorate at low concentrations. However, the method should be robust, and should be easily transferable to a water utility laboratory. The types of methods that might be considered, but are not limited to, include:

- Capillary electrophoresis
- Bioassay methods
- Amperometric detectors
- Selective reagent methods

The project should start with a comprehensive literature review on the proposed analytical methods and should also cover the existing understanding of perchlorate chemistry. It is anticipated that a minimum of four potential methods should be screened in this project. Further screening should be conducted with a matrix of requirements to rank the potential analytical methods with respect to likelihood of success. Two or three analytical methods most likely of success should be pursued for detailed development. The final report should propose detailed procedures for the recommended method.

TITLE: INTER-LABORATORY STUDY FOR THE PERFORMANCE EVALUATION OF THE CALIFORNIA DHS METHOD: DETERMINATION OF PERCHLORATE BY ION CHROMATOGRAPHY

Description of Problem: A method for the determination of perchlorate by ion chromatography (IC) has been recently developed by the California Department of Health Services (CDHS). However, the inter-laboratory accuracy and precision of the method has not yet been determined. This method performance information will be critical for regulatory decisions made for perchlorate detected near and at the level of concern.

Objective of Research Response: Conduct an inter-laboratory performance evaluation study of the method for the determination of perchlorate by IC. The study should evaluate the inter-laboratory accuracy and precision of the method, with data and results published in a final document.

Recommended Funding: \$128,000, including both research costs as well as AWWARF administrative costs.

Past and Ongoing Related Research: The new IC method for analysis of the perchlorate ion was developed by the CDHS in 1997. Therefore, there is relatively little research information available in the literature regarding this method. The CDHS should be contacted for information and data related to development of this new method, as well as for the method protocol. Similarly, the CDHS has an approval process for commercial laboratories that are doing perchlorate analyses. The approval process, as well as the data submitted by the commercial laboratories is potentially relevant information to this performance survey. The EPA is currently doing an evaluation study of the CDHS IC method and should be contacted for relevant information. The United States Air Force (USAF) is also conducting a peer review study of the new CDHS ion chromatography method and should also be contacted for relevant information. With the exception of the CDHS IC protocol, all of the above studies are ongoing with no published results to date.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The first controversial issue is that perchlorate contamination in the environment is seen by many as a California-specific issue. The second controversial issue is that there are no known enforceable regulations that address perchlorate contamination of drinking water in any state. Similarly, the EPA does not have an enforceable standard for this contaminant.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

- | | | | |
|---|--|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input checked="" type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input type="checkbox"/> Congress | <input type="checkbox"/> Education | <input checked="" type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum: Check one.

- | | | | |
|---|---|---|-------------------------------------|
| <input type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input checked="" type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

The CDHS method for perchlorate analysis by IC has been available since June 1997. Water utilities that are vulnerable to perchlorate contamination have a critical need to monitor their water supplies for this compound. Therefore, the CDHS method has seen wide-spread use. However, very limited data are available on inter-laboratory performance or the accuracy and precision of this method.

RESEARCH APPROACH

Researchers must be experienced in conducting inter-laboratory performance evaluation studies of laboratory analytical methods. The contractor will supply all performance evaluation samples and will perform the statistical evaluation of the study results. The study should include a variety of water matrices and perchlorate concentration ranges from the quantitation level, regulatory level of concern, up to ten times the regulatory level of concern.

TITLE: FATE AND TRANSPORT OF PERCHLORATE IN DRINKING WATER SOURCES

Description of Problem: The location, concentration and natural matrix of perchlorate is unknown in aquifers being used to provide drinking water. Without knowing where perchlorate is located new wells may be drilled into a contaminated aquifer. Additionally, transport prognosis can provide lead-times for installation of treatment technology at, as yet, uncontaminated sites.

Objective of Research Response: Develop retardation factors and other inputs for use in existing computer models to forecast the movement and future location of perchlorate contamination in a variety of aquifer types.

Recommended Funding: \$577,000, including both research costs as well as AWWARF administrative costs.

Past and Ongoing Related Research: The fate and transport of chlorinated solvents and dense non-aqueous liquid phase solvents in the subsurface has been studied by various government, research, and industry entities. The protocols established by these investigations may greatly shorten the time required to develop methodologies to address the subsurface and transport of perchlorate. In addition, a method of identifying locations at risk of having environmental perchlorate contamination is under development by the United States Air Force. However, this Air Force work does not address the fate and transport of perchlorate contamination in the aquifers, which is the focus of this study. Major Dan Rogers of Wright-Patterson Air Force Base is a contact on this Air Force work. Similarly, Joe Silversteen of the National Exposure Research Laboratory is investigating the movement of perchlorate in the environment. This project should be coordinated with these other projects to avoid overlap of the research efforts.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The first controversial issue is that perchlorate contamination in the environment is seen by many as a California-specific issue. The second controversial issue is that there are no known enforceable regulations that address perchlorate contamination of drinking water in any state. Similarly, the EPA does not have an enforceable standard for this contaminant.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

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|---|---|--|--|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input checked="" type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input checked="" type="checkbox"/> AWWA | <input checked="" type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input checked="" type="checkbox"/> Congress | <input type="checkbox"/> Education | <input checked="" type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|---|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input type="checkbox"/> Public affairs | <input checked="" type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|---|---|---|--|
| <input type="checkbox"/> Proof of concept | <input checked="" type="checkbox"/> Develop application | <input checked="" type="checkbox"/> Laboratory test | <input checked="" type="checkbox"/> Pilot test |
| <input checked="" type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

Previous studies have been conducted on other contaminants in groundwater used for domestic purposes. Because perchlorate is a highly soluble substance its affinity to travel in groundwater is very high. Detection levels have improved to the extent that detection at low concentrations will provide improved tracking capabilities.

RESEARCH APPROACH

Already developed sensing equipment using modified cone penetrometers may provide a mobile method of detection and mapping of perchlorate contamination. Use of transport and diffusion models may likewise contribute to the development of improved models to predict the movement of the perchlorate plume. Develop criteria and parameters to be used for application of already existing groundwater models.

Task 1, which is an occurrence survey, will focus on the identification of drinking water utilities at risk of being impacted by perchlorate-contaminated source water. Considerable empirical knowledge has been developed in California and Nevada regarding locations impacted by perchlorate. This information, combined with additional information on locations where perchlorate has likely been used in substantial quantities, can be used to develop a matrix of parameters to assess the likelihood of perchlorate contamination.

TASK 1 - Occurrence Study

- Review existing literature
- Identify major users of perchlorate both past and present
- Identify and determine gaps in occurrence knowledge
- Develop matrix to evaluate potential for perchlorate contamination at a water utility
- Set-up sampling study
- Assess water utilities across the country using the matrix
- Prepare occurrence report

TASK 2 - Laboratory Study

- Determine behavior of perchlorate with different types of soil and substrata materials addressing the range of values for the following parameters:
 - Complexation behavior with humic and fulvic materials
 - Retardation factors
 - Adsorption to soils of high and low cation and anion exchange capacity
 - Movement characteristics in various media

TASK 3. Field Evaluation

- Identify two to three contaminated basins which can be used to calibrate the computer models
- Verify the model prediction and identify any necessary modifications
- Produce a technical report that can be used as an owners' manual for application of the program to perchlorate contamination

TITLE: ASSESS THE CURRENT REGIONAL HEALTH EFFECTS ASSOCIATED WITH PERCHLORATE IN GROUND AND SURFACE WATER SUPPLIES

Description of Problem: Until recently, population centers or communities were unknowingly drinking water with possibly significant levels of perchlorate contamination. A provisional action level of 18 micrograms per liter was adopted by the California Department of Health Services (CDHS) for this contaminant. People have been drinking water at or near this level for several years; adverse effects may be non-existent or may have been overlooked. Currently, there are no epidemiological data to determine the extent of any adverse effects of perchlorate.

Objective of Research Response: To gather health data on the affected populations to determine if perchlorate has had adverse health effects.

Recommended Funding: Approximately \$1,090,000 which includes research costs as well as AWWARF project management costs.

Past and Ongoing Related Research: Currently, there are no specific data on the health effects associated with drinking low-concentration perchlorate-contaminated water. The EPA has compiled several studies that monitored the health effects of perchlorate on the thyroid. Health-effects studies are currently getting underway that will encompass a two-generation study on rats. In addition, the Agency for Toxic Substances and Disease Registry (ATSDR), in conjunction with the Air Force and the CDHS, is formulating an epidemiological study to be conducted in the Sacramento area. This study will investigate the possible health effects associated with drinking perchlorate-contaminated water in that area. However, although this single study is being conducted, there is a need for additional studies to be conducted in other areas where perchlorate-contaminated drinking water may have been consumed for some time (such as Boulder City, Nevada). In addition, although the study being conducted in the Sacramento area is addressing the main issues related to possible epidemiological impacts of perchlorate, there are other health-related issues that should also be addressed in additional studies. Major Dan Rogers of the United States Air Force (USAF) is a contact for current information on the status of ongoing epidemiological as well as health-effects studies related to perchlorate.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The first controversial issue is that perchlorate contamination in the environment is seen by many as a California-specific issue. The second controversial issue is that there are no known enforceable regulations that address perchlorate contamination of drinking water in any state. Similarly, the EPA does not have an enforceable standard for this contaminant.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada,

approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

- | | | | |
|---|---|--|---|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input checked="" type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input checked="" type="checkbox"/> Congress | <input checked="" type="checkbox"/> Education | <input checked="" type="checkbox"/> Environmental Groups | <input checked="" type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|--|---|---|---|
| <input type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input checked="" type="checkbox"/> Public affairs | <input checked="" type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|---|---|---|-------------------------------------|
| <input type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input checked="" type="checkbox"/> Product development | |

BACKGROUND

Studies are being done in the Sacramento area and future studies should be done in other areas with perchlorate contamination.

RESEARCH APPROACH

This research should be accomplished through a cooperative effort with Federal, State, and local health and epidemiological research agencies. Identify current research being conducted and funded, and identify communities to be studied using occurrence data. Determine the current concentrations of perchlorate in the water and estimate past concentrations. Identify health effect data such as medical records, collect data and evaluate health effects, and attempt to also identify sensitive populations. Determine if adverse health effects traceable to perchlorate in drinking water can be identified.

This project could be conducted as a collaborative project with other supporters such as ATSDR, the USAF, EPA, etc.

TITLE: PERCHLORATE TELECONFERENCE

Description of Problem: Perchlorate is a relatively new contaminant. The water industry, regulatory industry and members of the public are unfamiliar with the compound, its health effects, treatment methods, and waste stream handling and disposal.

Objective of Research Response: Inform the water utility and regulatory communities of the knowledge and experience gained in California and Nevada in dealing with perchlorate. Identify likely sources of contamination. Inform the audience of concerns, research being done; and recommend local response to the possible presence of perchlorate contamination.

Recommended Funding: Approximately \$50,000.

Past and Ongoing Related Research: Projects of potential interest to this teleconference include research projects on: perchlorate occurrence, health effects, treatment methods, and perchlorate waste stream handling.

The California Department of Health Services (CDHS) developed the new ion chromatography method for analysis of the perchlorate ion in 1997. Since this new method has been used to identify most of the areas that are impacted by low concentrations of perchlorate contamination, there is also relatively little information on the occurrence of this contaminant across the country. However, a number of studies are anticipated or just started that will advance our understanding in this area. These studies include an anticipated AWWARF-funded occurrence survey project, as well as additional occurrence work being conducted by the United States Air Force (USAF).

Currently there are no specific data on the health effects associated with drinking low-concentration perchlorate-contaminated water. The EPA has compiled several studies that monitored the health effects of perchlorate on the thyroid. Health-effects studies are also currently getting underway (funded by the USAF) which will encompass a two-generation study on rats. In addition, the Agency for Toxic Substances and Disease Registry (ATSDR), in conjunction with the Air Force and the California Department of Health Services, is formulating an epidemiological study to be conducted in the Sacramento area. This study will investigate the possible health effects associated with drinking perchlorate-contaminated water in that area.

Aerojet and the USAF at Tyndall Air Force Base have done limited research on the treatment of perchlorate. The Aerojet study started with a screening of treatment technologies, and devoted considerable development effort to ion exchange treatment of perchlorate. However, the Aerojet work and the Air Force work both ended with the development of a biological treatment process. These biological treatment processes are not identical. In addition, a screening of treatment technologies to address low concentrations of perchlorate contamination in groundwater is currently being conducted for the Region IX EPA. A report, "Draft Technology Screening for the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin," which is expected to be updated soon, is available.

At this time there are no known studies that specifically address the issue of disposal of perchlorate-containing residuals from the water treatment process. However, the funding of some studies by AWWARF on this issue are anticipated within the next year. The current status of all of the relevant studies should be used in preparing the final agenda for the teleconference.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: Uncertainty of all related data on method, treatment, occurrence, and health effects.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

- | | | | |
|---|---|--|---|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input checked="" type="checkbox"/> AWWA | <input checked="" type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input checked="" type="checkbox"/> Manufacturers |
| <input checked="" type="checkbox"/> Congress | <input type="checkbox"/> Education | <input checked="" type="checkbox"/> Environmental Groups | <input type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|--|---|--|---|
| <input checked="" type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input checked="" type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input checked="" type="checkbox"/> Public affairs | <input checked="" type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|---|--|--|-------------------------------------|
| <input type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input checked="" type="checkbox"/> Implementation barrier | <input type="checkbox"/> Product development | |

BACKGROUND

Perchlorate (as ammonium perchlorate) is used in solid rocket propellants and has been found in a number of California and Nevada drinking water supplies in 1997. Sources of this contaminant are aerospace material and munitions development, testing, and manufacturing, as well as fireworks manufacturing. CDHS has established a provisional action level of 18 micrograms per liter for perchlorate in drinking water. Twenty-four water suppliers in California have found perchlorate in their source water above 18 micrograms per liter, and at levels ranging up to 280 micrograms per liter or higher. Perchlorate has been found in the Colorado River in Lake Mead at levels of approximately 11 micrograms per liter (Southern Nevada Water Authority). This Nevada source affects over 18 million people. Water utility and regulatory personnel have had to learn about perchlorate while finding limited information on its health effects, treatability, and waste disposal.

RESEARCH APPROACH

The teleconference would present an opportunity to reach a large segment of the water and regulatory industry with the most up-to-date knowledge of the issue. Specific areas that would be covered include: occurrence data, health effects, treatability, regulatory update, and waste stream handling and disposal. The goal of the Teleconference will be to initiate the transfer of scientific information that has been generated to date to the regulatory community and water utilities so that the process of assessing the national significance can begin. The interactive nature of teleconferences as typically conducted by AWWA would make this an extremely useful tool to allow education of those utility managers involved in the teleconference.

It is anticipated that this teleconference would be a collaborative effort between AWWA and the EPA.

TITLE: DEVELOP LITERATURE DATABASE AND COMMUNICATION TOOLS AND DISTRIBUTE TO WATER UTILITIES TO KEEP CUSTOMERS INFORMED OF PERCHLORATE ISSUES

Description of Problem: Perchlorate is a relatively new contaminant. Little is known about it by water utilities regarding health effects, possible treatment techniques, analytical methods and overall occurrence.

Objective of Research Response: To gather information regarding perchlorate and develop it for use in web sites and fact sheets, AWWA Journal articles, and other information sources that would be transmitted to utilities for distribution to customers.

Recommended Funding: Approximately \$75,000.

Past and Ongoing Related Research: A few fact sheets and web sites exist (California Department of Health Services, Las Vegas Valley Water District, etc.) but very little information has been distributed to utilities nationwide. Projects of potential interest to this teleconference include research projects on: perchlorate occurrence, health effects, treatment methods, and perchlorate waste stream handling.

The California Department of Health Services (CDHS) developed the new ion chromatography method for analysis of the perchlorate ion in 1997. Since this new method has been used to identify most of the areas that are impacted by low concentrations of perchlorate contamination, there is also relatively little information on the occurrence of this contaminant across the country. However, a number of studies are anticipated or just started that will advance our understanding in this area. These studies include an anticipated AWWARF-funded occurrence survey project, as well as additional occurrence work being conducted by the United States Air Force (USAF).

Currently there are no specific data on the health effects associated with drinking low-concentration perchlorate-contaminated water. The EPA has compiled several studies that monitored the health effects of perchlorate on the thyroid. Health-effects studies are also currently getting underway (funded by the USAF) which will encompass a two-generation study on rats. In addition, the Agency for Toxic Substances and Disease Registry (ATSDR), in conjunction with the Air Force and the California Department of Health Services, is formulating an epidemiological study to be conducted in the Sacramento area. This study will investigate the possible health effects associated with drinking perchlorate-contaminated water in that area.

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the Treatability of Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin," which is expected to be updated soon, is available.

At this time there are no known studies that specifically address the issue of disposal of perchlorate-containing residuals from the water treatment process. However, the funding of some studies by AWWARF on this issue are anticipated within the next year. The current status of all of the relevant studies should be used in preparing the final agenda for the teleconference.

Proposal Source: Perchlorate Issue Group.

Controversial Issues: The first controversial issue is that perchlorate contamination in the environment is seen by many as a California-specific issue. The second controversial issue is that there are no known enforceable regulations that address perchlorate contamination of drinking water in any state. Similarly, the EPA does not have an enforceable standard for this contaminant.

Staff Comments: Perchlorate contamination has been found to be much more widespread than anticipated. Although most sites with perchlorate contamination have an easily identified link to the solid rocket motor industry, a number of sites with perchlorate contamination have no known perchlorate-related history. Further, based on limited sampling in California and Nevada, approximately 18 million people are already impacted by perchlorate contamination of drinking water.

Audience:

- | | | | |
|---|---|--|---|
| <input checked="" type="checkbox"/> Utilities | <input checked="" type="checkbox"/> Regulators | <input type="checkbox"/> Research Community | <input type="checkbox"/> Consultant |
| <input type="checkbox"/> AWWA | <input checked="" type="checkbox"/> Other Orgs. | <input type="checkbox"/> Collaborative Partners | <input type="checkbox"/> Manufacturers |
| <input checked="" type="checkbox"/> Congress | <input checked="" type="checkbox"/> Education | <input checked="" type="checkbox"/> Environmental Groups | <input checked="" type="checkbox"/> AWWARF (internal) |

Utility Audience:

- | | | | |
|--|---|---|---|
| <input checked="" type="checkbox"/> Manager | <input checked="" type="checkbox"/> Water quality | <input type="checkbox"/> Design and engineering | <input type="checkbox"/> Administration |
| <input checked="" type="checkbox"/> Public affairs | <input checked="" type="checkbox"/> Operations | <input type="checkbox"/> Other _____ | |

Position on Research Continuum:

- | | | | |
|---|---|---|-------------------------------------|
| <input type="checkbox"/> Proof of concept | <input type="checkbox"/> Develop application | <input type="checkbox"/> Laboratory test | <input type="checkbox"/> Pilot test |
| <input type="checkbox"/> Full-scale test | <input type="checkbox"/> Implementation barrier | <input checked="" type="checkbox"/> Product development | |

BACKGROUND

Information tools are needed to keep utilities and their customers informed regarding important issues. Tools that were developed to keep utilities and customers informed for "contaminants" such as *cryptosporidium* need to be developed for perchlorate. This project would develop and distribute such tools.

RESEARCH APPROACH

A fact sheet and web site that summarizes current information, studies and known health implications should be developed and distributed. When study results are released or new studies are initiated, the results and new programs should be summarized and simplified, if needed, allowing utilities and customers to understand the implications of recent developments.

Task 1: Database development - Computer Based Program; time frame: three months to be accomplished by consultant.

Task 2: Communication Tools; time frame: three months to be accomplished by consultant

- Web page
- Fact sheet
- Layman's guide
- News releases

While the AWWA Research Foundation is taking the lead in implementation of perchlorate research for drinking water, this type of informational effort anticipated for this project is normally within the scheme of activities conducted by AWWA. Future updates and tools would be done by AWWA staff.

APPENDIX 1

Perchlorate Research Issue Group

Ontario, California

September 30 - October 2, 1997

Purpose: Develop a multi-year research plan which addresses perchlorate in drinking water, with a focus on treatment and analytical methodology issues.

Tuesday, Sept. 30

1:00

Opening Session

Welcome

Bob Martin

Background

Deborah Brink

Introductions; ground rules; schedule overview

Jack Mannion

2:15

Break

2:30 General Session: Familiarization Briefings

I. Summary of current conclusions
about health effects

Major Dan Rogers

II. Occurrence: current knowledge; new study

Frank Blaha

III. The new analytical method: reliability; issues and questions

Joe Donnelly

IV. Status report and briefing on aerojet bioremediation

Mike Girard

V. Status report and briefing on Air Force bioremediation

Jim Hurley

3:45 Break

VI. Lawrence-Livermore research

Ravi Upadhye

VII. Summary overview of prospects for other treatment technologies (e.g. GAC, ion exchange, others).

Kevin Mayer

4:45 General Session: Group Discussion

Presentation of proposed approach to plan development; group discussion to confirm or modify. Review of tomorrow's tasks and schedule.

5:30 Adjourn

6:30 Reception and dinner

Wednesday, Oct. 1

7:45 Continental Breakfast

8:30 General Session

Review of plan for the day.

Participants choose which small group they wish to join:

--Analytical Methods

What research (and other actions) may be needed to gain official acceptance of proposed methods?

--Utility Requirements

What criteria must treatment and waste disposal methods meet to insure practicality, reliability, and acceptability?

--Treatment Options

Which treatment methods offer the most promise and merit further work and investment? What further work is needed to demonstrate efficacy and reliability? What disposal issues must be addressed for the treatment methods?

Instructions on small group tasks and procedures.

9:00 Small Group Meetings

10:00 Break

10:15 Small Groups Continue

Groups to come back with general data gap summary and short, one paragraph description of general type of research projects needed.

11:00 General Session

(NOTE: Facilitator will check with group leaders at break to confirm this time or negotiate an earlier or later start for the general session.)

Report on each small group discussion, followed by group discussion, leading to general agreement on conclusions/recommendations.

12:15 Lunch

1:30 General Session

(Any follow-up to previous general session that may be necessary.)

Organization of new small groups to develop project descriptions. Groups will be set up according to the research topics/needs generally agreed to; each group will likely have a cluster or series of related projects.

Participants choose which group they want to be in.

Instructions on small group tasks and use of project descriptions form. Brief discussion of objective/approach for project descriptions.

2:15 Small Group Meetings

Small group tasks (with suggested time for each):

- 1) Review projects to be developed, defining scope and other guidance for those who will write them up. (30-45 min.)
- 2) Organize teams to draft project descriptions. (10 min.)
- 3) Teams draft descriptions (90 min.) and bring them to small group for review and refinement (60 min.)
- 4) Teams polish draft descriptions and submit them to staff by 6:00 p.m.

(Note: Teams take breaks at their own discretion. Staff collects project descriptions and reproduces them for everyone. Copies given to hold for pick-up after dinner.)

6:00 Adjourn for day

(Evening free. Participants pick up project descriptions after dinner, to review them before morning session.)

Thursday, Oct. 2

7:30 Continental Breakfast

8:00 General Session: Project Review

Discussion of project descriptions. Only major comments of significance are brought to group; lesser suggestions/editing to be submitted in writing (i.e. notes made on each description during review.)

10:00 Break and Checkout

10:30 General Session: Prioritization and Scheduling

Large group ranking of projects; negotiation of timing/sequence over five year period.

11:45 Evaluation and Wrap-up

12:30 Workshop Adjourns

APPENDIX 2

PERCHLORATE ISSUE GROUP

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